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Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Volume X. Cement Industry Report

Arthur D. Little, Inc, Cambridge, Mass.

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ENVIRONMENTAL CONSIDERATIONS OF SELECTED ENERGY CONSERVING MANUFACTURING PROCESS OPTIONS:

Vol. X. Cement Industry Report

Interagency
Energy-Environment
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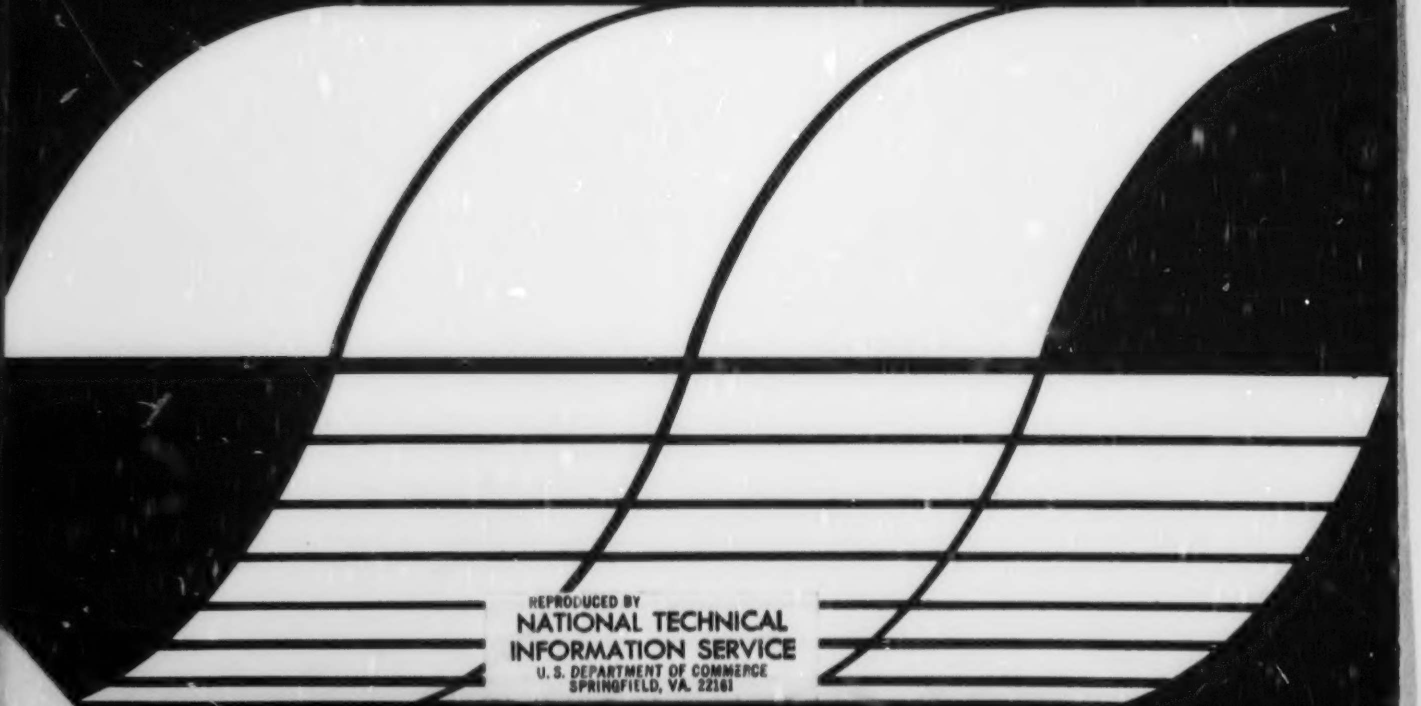

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16. ABSTRACT

This study assesses the likelihood of new process technology and new practices being introduced by energy intensive industries and explores the environmental impacts of such changes.

Specifically, Vol. X deals with the cement industry and examines four options: (1) suspension preheater, (2) flash calciner, (3) fluid-bed cement process, and (4) conversion to coal fuel from oil and natural gas, all in terms of process economics and environmental/energy consequences. Vol. III-IX and Vol. XI-XV deal with the following industries: iron and steel, petroleum refining, pulp and paper, olefins, ammonia, aluminum, textiles, glass, chlor-alkali, phosphorus and phosphoric acid, copper, and fertilizers. Vol. I presents the overall summation and identification of research needs and areas of highest overall priority. Vol. II, prepared early in the study, presents and describes the overview of the industries considered and presents the methodology used to select industries.

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ENVIRONMENTAL CONSIDERATIONS OF SELECTED ENERGY CONSERVING MANUFACTURING PROCESS OPTIONS

Volume X

CEMENT INDUSTRY REPORT

EPA Contract No. 68-03-2198

Project Officer

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This study, consisting of 15 reports, identifies promising industrial processes and practices in 13 energy-intensive industries which, if implemented over the coming 10 to 15 years, could result in more effective utilization of energy resources. The study was carried out to assess the potential environmental/energy impacts of such changes and the adequacy of existing control technology in order to identify potential conflicts with environmental regulations and to alert the Agency to areas where its activities and policies could influence the future choice of alternatives. The results will be used by the EPA's Office of Research and Development to define those areas where existing pollution control technology suffices, where current and anticipated programs adequately address the areas identified by the contractor, and where selected program reorientation seems necessary. Specific data will also be of considerable value to individual researchers as industry background and in decision-making concerning project selection and direction. The Power Technology and Conservation Branch of the Energy Systems-Environmental Control Division should be contacted for additional information on the program.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

EXECUTIVE SUMMARY

The manufacture of cement in the United States required 0.52 x 10^{15} Btu in 1971. This ranked cement as the eighth most energy intensive industry at that time. The production of cement in 1972 totaled 84.6 million tons, with portland cement constituting 96% of this amount, and the balance being natural, masonry, and pozzolan cements. This cement had a value of about $3.5 billion, and was produced by 50 cement companies, which operated 150 plants.

Approximately 80% of the total energy required for cement manufacture is fuel, which is required for the high-temperature reaction step of clinker production. The balance is electrical energy primarily used in grinding the raw materials and the finished cement. Presently, coal, oil, and natural gas are all used for cement production. During the past several decades, coal has been declining in use, as it was progressively displaced by oil and natural gas. In the 1970's, this trend has been reversed.

Coal is an acceptable fuel for cement manufacture, both technologically and environmentally. Coal can replace all of the oil and gas now being used by the cement industry. Most of the industry's rotary kilns (in which most of the fuel is burned), can be converted to coal firing. Almost all of the fuel's sulfur leaves the cement process chemically bound up as part of the cement product and the waste kiln dust.

This study of possible process modifications or the use of alternative fuel forms in the cement industry focused on the unit process of clinker production, since it requires about 80% of the total energy for cement manufacture. The process modifications analyzed in this study were the suspension preheater, flash calciner, and fluidized-bed cement process. The use of coal instead of oil or gas was also considered.

All of the process options investigated will require less fixed capital investment and use less total energy than the long rotary kiln base case. The pollution control costs are also expected to be lower for these process options. It appears that the amount and nature of effluents from these process options will be the same or less than from the long rotary kiln.

The conversion from oil or gas fuel to coal will require additional capital for the coal storage and handling. Fugitive emissions and runoff from coal storage and handling are expected to increase pollution control costs.

This report was submitted in partial fulfillment of contract 68-03-2198 by Arthur D. Little, Inc. under sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 9, 1975 to February 9, 1976.

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Dr. Herbert S. Skovronek, Project Officer, was a valuable resource to us throughout the study. He not only supplied us with information on work presently being done in other branches of EPA and other government agencies, but served as an indefatigable guide and critic as the study progressed. His advisors within EPA, FEA, DOC, and NBS also provided us with insights and perspectives valuable for the shaping of the study.

During the course of the study we also had occasion to contact many individuals within industry and trade associations. Where appropriate we have made reference to these contacts within the various reports. Frequently, however, because of the study's emphasis on future developments with comparative assessments of new technology, information given to us was of a confidential nature or was supplied to us with the understanding that it was not to be credited. Therefore, we extend a general thanks to all those whose comments were valuable to us for their interest in and contribution to this study.

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ENGLISH-METRIC (SI) CONVERSION FACTORS

To Convert From	To	Multiply By
Acre	Metre^2	4,046
Atmosphere (normal)	Pascal	101,325
Barrel (42 gal)	Metre^3	0.1589
British Thermal Unit	Joule	1,055
Centipoise	Pascal-second	0.001
Degree Fahrenheit	Degree Celsius	$t_C^\circ = (t_F^\circ - 32)/1.8$
Degree Rankine	Degree Kelvin	$t_K^\circ = t_R^\circ/1.8$
Foot	Metre	0.3048
Foot^3/minute	Metre^3/sec	0.0004719
Foot^3	Metre^3	0.02831
Foot^2	Metre^2	0.09290
Foot/sec	Metre/sec	0.3048
Foot^2/hr	Metre^2/sec	0.00002580
Gallon (U.S. liquid)	Metre^3	0.003785
Horsepower (550 ft-lbf/sec)	Watt	745.7
Horsepower (electric)	Watt	746.0
Horsepower (metric)	Watt	735.5
Inch	Metre	0.02540
Kilowatt-hour	Joule	3.60×10^6
Litre	Metre^3	1.000×10^{-3}
Micron	Metre	1.000×10^{-6}
Mil	Metre	0.00002540
Mile (U.S. statute)	Metre	1,609
Poise	Pascal-second	0.1000
Pound force (avdp)	Newton	4.448
Pound mass (avdp)	Kilogram	0.4536
Ton (assay)	Kilogram	0.02916
Ton (long)	Kilogram	1,016
Ton (metric)	Kilogram	1,000
Ton (short)	Kilogram	907.1
Tonne	Kilogram	1,000

Source: American National Standards Institute, "Standard Metric Practice Guide," March 15, 1973. (ANS72101-1973) (ASTM Designation E380-72)

I. INTRODUCTION

A. BACKGROUND

Industry in the United States purchases about 27 quads* annually, approximately 40% of total national energy usage.** This energy is used for chemical processing, raising steam, drying, space cooling and heating, process stream heating, and miscellaneous other purposes.

In many industrial sectors energy consumption can be reduced significantly by better "housekeeping" (i.e., shutting off standby furnaces, better thermostat control, elimination of steam and heat leaks, etc.) and greater emphasis on optimization of energy usage. In addition, however, industry can be expected to introduce new industrial practices or processes either to conserve energy or to take advantage of a more readily available or less costly fuel. Such changes in industrial practices may result in changes in air, water or solid waste discharges. The EPA is interested in identifying the pollution loads of such new energy-conserving industrial practices or processes and in determining where additional research, development, or demonstration is needed to characterize and control the effluent streams.

B. CRITERIA FOR INDUSTRY SELECTION

In the first phase of this study we identified industry sectors that have a potential for change, emphasizing those changes which have an environmental/energy impact.

Industries were eliminated from further consideration within this assignment if the only changes that could be envisioned were:

- energy conservation as a result of better policing or "housekeeping,"
- better waste heat utilization,
- fuel switching in steam raising, or
- power generation.

---

*1 quad = 10^{15} Btu

**Purchased electricity valued at an approximate fossil fuel equivalence of 10,500 Btu/kWh.

After discussions with the EPA Project Officer and his advisors, industry sectors were selected for further consideration and ranked using:

- Quantitative criteria based on the gross amount of energy (fossil fuel and electric) purchased by industry sector as found in U.S. Census figures and from information provided from industry sources. The cement industry purchased 0.52 quads out of the 12.14 quads purchased in 1971 by the 13 industries selected for study, or 2% of the 27 quads purchased by all industry (see Table I-1).

- Qualitative criteria relating to probability and potential for process change, and the energy and effluent consequences of such changes.

In order to allow for as broad a coverage of technologies as possible, we then reviewed the ranking, eliminating some industries in which the process changes to be studied were similar to those in another industry planned for study. We believe the final ranking resulting from these considerations identifies those industry sectors which show the greatest possibility of energy conservation via process change. Further details on this selection process can be found in the Industry Priority Report prepared under this contract (Volume II). On the basis of this ranking method, the cement industry appeared in eighth place among the 13 industrial sectors listed.

TABLE I-1

SUMMARY OF 1971 ENERGY PURCHASED IN SELECTED INDUSTRY SECTORS

	Industry Sector	10^{15} Btu/Yr	SIC Code In Which Industry Found
1.	Blast furnaces and steel mills	3.49(1)	3312
2.	Petroleum refining	2.96(2)	2911
3.	Paper and allied products	1.59	26
4.	Olefins	0.984(3)	2818
5.	Ammonia	0.63(4)	287
6.	Aluminum	0.59	3334
7.	Textiles	0.54	22
8.	Cement	0.52	3241
9.	Glass	0.31	3211, 3221, 3229
10.	Alkalies and chlorine	0.24	2812
11.	Phosphorus and phosphoric acid production	0.12(5)	2819
12.	Primary copper	0.081	3331
13.	Fertilizers (excluding ammonia)	0.078	287

(1) Estimate for 1967 reported by FEA Project Independence Blueprint, p. 6-2, USGPO, November 1974.

(2) Includes captive consumption of energy from process byproducts (FEA Project Independence Blueprint)

(3) Olefins only, includes energy of feedstocks: ADL estimates

(4) Amonia feedstock energy included: ADL estimates

(5) ADL estimates

Source: 1972 Census of Manufactures, FEA Project Independence Blueprint, USGPO, November 1974, and ADL estimates.

C. CRITERIA FOR PROCESS SELECTION

Within each of the 13 industry sectors, there are a variety of potential changes in industrial practice. In this study we have focused on identifying changes in the primary production processes which have clearly defined pollution consequences. In selecting those to be included in this study, we have considered the needs and limitations of the EPA as discussed more completely in the Industry Priority Report mentioned above. Specifically, energy conservation has been defined broadly to include, in addition to process changes, conservation of energy or energy form (gas, oil, coal) by a process or feedstock change. Natural gas has been considered as having the highest energy form value followed in descending order by oil, electric power, and coal. Thus, a switch from gas to electric power would be considered energy conservation because electric power could be generated from coal, existing in abundant reserves in the United States when compared to natural gas. Moreover, pollution control methods resulting in energy conservation have been included within the scope of this study. Finally, emphasis has been placed on process changes with near-term rather than long-term potential within the 15-year span of time of this study.

In addition to excluding from consideration better waste heat utilization, "housekeeping," power generation, and fuel switching, as mentioned above, certain options have been excluded to avoid duplicating work being funded under other contracts and to focus this study more strictly on "process changes." Consequently, the following have also not been considered to be within the scope of work:

- Carbon monoxide boilers (however, unique process vent streams yielding recoverable energy could be mentioned);
- Fuel substitution in fired process heaters;
- Mining and milling, agriculture, and animal husbandry;
- Substitution of scrap (such as iron, aluminum, glass, reclaimed textiles, and paper) for virgin materials;
- Production of synthetic fuels from coal (low- and high-Btu gas, synthetic crude, synthetic fuel oil, etc.); and
- All aspects of industry-related transportation (such as transportation of raw material).

D. SELECTION OF CEMENT INDUSTRY PROCESS OPTIONS

Within each industry, the magnitude of energy use was an important criterion in judging where the most significant energy savings might be realized, since reduction in energy use reduces the amount of pollution generated in the energy production step. Guided by this consideration, candidate options for in-depth analysis were identified from the major energy consuming process steps with known or potential environmental problems.

After developing a list of candidate process options, we assessed subjectively

- pollution or environmental consequences of the process change,
- probability or potential for the change, and
- energy conservation consequences of the change.

Even though all of the candidate process options were large energy users, there was wide variation in energy use and estimated pollution loads between options at the top and bottom of the list. A modest process change in a major energy consuming process step could have more dramatic energy consequences than a more technically significant process change in a process step whose energy consumption is rather modest. For the lesser energy-using process steps process options were selected for in-depth analysis only if a high probability for process change and pollution consequences was perceived.

Because of the time and scope limitations for this study, we have not attempted to prepare a comprehensive list of process options or to consider all economic, technological, institutional, legal or other factors affecting implementation of these changes. Instead we have relied on our own background experience, industry contacts, and the guidance of the Project Officer and EPA advisors to choose eight promising process options (with an emphasis on near-term potential) for study in the cement industry:

- Suspension preheater
- Flash calciner
- Fluidized-bed cement process
- Conversion to coal fuel from oil and natural gas
- Roller mill for raw material grinding
- Oxygen enrichment of kiln combustion air
- New cement process which uses no pyroprocessing step
- Use of slag and other pozzolanic additives to portland cement.

After discussion with the EPA Project Officer, his advisors, and industry representatives, the first four of these options were chosen for in-depth analysis because:

- They represent technology that can be implemented in the near term,
- The promise of energy savings is significant, and therefore could motivate the industry to implement the technology, and
- There is a recognized or expected effect upon effluent streams with attendant environmental impact.

In this study, the cement industry description is based on 1974, the latest representative year for the industry for which we had good statistical information. Recognizing that capital investments and energy costs have escalated rapidly in the past few years and have greatly distorted the traditional basis for making cost comparisons, we developed costs representative of the first half of 1975, using constant 1975 dollars for our comparative analysis of new and current processes.

II. FINDINGS, CONCLUSIONS, RECOMMENDATIONS

A. APPROACH

The changes in portland cement technology and cement industry practices examined in this study have an effect on only one of the major cement-making process steps, the clinkering, or cement burning, step. The major new developments in cement technology and plant practice are focused on this single process step because it uses 70-80% of the total energy required for cement manufacture.

Although some major departures from conventional cement making by pyroprocessing are currently under investigation, the only changes with a reasonably high probability of implementation during the next 15 years are those which exist today and are the product of a considerable number of years of active development. Further, these new technologies or alternatives to present state-of-the-art in clinker production, with the exception of the production of cement clinker in a fluidized-bed reactor, are being implemented in commercial-scale facilities around the world.

Since the four process or practice alternatives considered in this study (suspension preheater, flash calciner, fluidized-bed reactor, and conversion to coal fuel) affect only the cement clinker production step, the design, layout, fixed capital investment, operating costs, effluent streams, and environmental aspects of the other processing steps will be essentially unchanged for cement plants operating today, and modified or new plants which employ these process or practice alternatives. Therefore, in this study we compare only the affected clinker production step represented by the current long rotary kiln (base line) and the alternative processes or practices: suspension preheater, flash calciner, fluidized-bed reactor, and conversion to coal fuel.

This study and analysis have shown that the quantities and compositions of the various effluent and process streams associated with these alternative processes and practices are essentially the same as those associated with the long rotary kiln (Tables II-1 and II-2). In all cases, a hydrocarbon fuel is burned with air to generate the heat required for cement clinker production. These combustion gases carry dust and volatilized elements from the reactor (i.e., rotary kiln or fluidized bed). The percent excess air, the chemical composition and the particle distribution of the particulates will change, but it appears that no new species of pollutants and no new effluent streams are created.

TABLE II-1

SUMMARY OF COSTS/ENERGY/ENVIRONMENTAL ASPECTS OF PROCESS OPTIONS IN THE PORTLAND CEMENT INDUSTRY

Base Line Process: New Cement Plant, Dry Process, Long Rotary Kiln

	PROCESS OPTIONS			
	SUSPENSION PREHEATER	FLASH CALCINER	FLUIDIZED BED	COAL FUEL
COSTS	Lower capital cost. Lower operating cost. Lower pollution control costs.	Lower capital cost; about the same as suspension preheater. Lower operating cost; lower pollution control costs.	Lower capital cost; lowest of these options. Lower operating cost. Pollution control costs about the same as base line process.	Higher capital cost due to coal storage & handling. Slightly lower operating cost due to lower fuel cost. Higher pollution control costs due to coal storage & handling.
ENERGY	Lower process energy requirements, primarily due to significantly lower fuel energy. About 20-25% overall energy saving.	Lower process energy requirements, primarily due to significantly lower fuel energy. About 20-25% overall energy saving.	Lower process energy due to generation of total electrical energy requirements from reactor exit gases.	Conservation due to use of coal instead of natural gas and oil for heat energy.
ENVIRONMENT	No change, except that waste dust recycled if alkali specifications in cement product can be met.	Lower NO_x. Other aspects are about the same as with suspension preheater. All waste dusts recycled if alkali specifications can be met.	Significantly less waste dust. Process has potential for converting waste rotary kiln dust into cement, which can reduce pollution control costs at existing plants. Lower NO_x. Waste dust almost pure alkali salts, with potential by-product value.	Fugitive emissions and rainwater runoff from coal handling and storage cause additional air and water pollution control costs. Coal ash combines with cement raw materials reducing environmental problems.

TABLE II-2

SUMMARY OF RESULTS OF PROCESS OPTIONS IN THE PORTLAND CEMENT INDUSTRY
(Basis: 1350 Tons Cement Per Day)
Base Line: Long Kiln (Oil) - Energy Consumption from 3.4 to 6×10^6 Btu/Ton

	Long Kiln (Oil)	Suspension Preheater & Flash Calciner	Fluidized Bed	Long Kiln (Coal)
PRODUCTION FACILITY				
Fixed Capital Investment ($\$10^6$)	42	40	38	45
Production Cost ($/ton)	47.81	43.71	44.30	45.56
Energy Requirements (10^6 Btu/ton)	5.6	4.2	5.0	5.6
ENVIRONMENTAL CONTROL FACILITIES				
Fixed Capital Investment ($\$10^6$)	1.6	1.2	1.9	2.0
Operating Cost ($/ton)	1.97	1.40	2.10	2.27
Energy Requirements (10^6 Btu/ton)	.069	.047	0.102	.069
PRODUCTION PLUS ENVIRONMENTAL CONTROL FACILITIES				
Fixed Capital Investment ($\$10^6$)	43.6	41.2	39.9	47.0
Operating Cost ($/ton)	49.78	45.11	46.40	47.83
Energy Requirements (10^6 Btu/ton)	5.7	4.2	5.1	5.7

The available literature presents insufficient data to permit us to compare the dust or particulate emissions from the clinkering step as a function of the chemical composition and nature of the raw materials and fuel inputs (especially the composition of the coal ash, or the mineral impurities in the coal burned as fuel) for each of the various alternative technologies. Also, no data are available to indicate the composition of the gases emitted to the atmosphere after passage through a suitable dust collector, such as a glass fabric filter or an electrostatic precipitator. Therefore, this final but important aspect of specific elemental or component material balancing cannot be accomplished. (See Section II-C for recommended research and development areas.)

B. POTENTIAL CONFLICT WITH ENVIRONMENTAL REGULATIONS

The changes in both cement industry practice and process technology which we have studied will not result in any potential conflict with the environmental regulations (see Appendix C). Significant environmental aspects of the industrial practice and process changes studied are summarized in the following subsections.

1. Suspension Preheater

Outside the United States, the suspension preheater-equipped rotary kiln is a well-developed, established cement clinker production step. Although it gained rapid acceptance in the United States in the 1950's, this clinkering alternative fell into total disfavor with the U.S. cement industry because of problems with the operation and the quality of the cement. However, the present high fuel costs combined with continued and apparently successful development and operation of the suspension preheater has led to its recent reacceptance. Due to extensive experience with actual commercial-scale operation in a large number of plants throughout the world, the environmental aspects of the suspension preheater-equipped rotary cement kiln are quite well known.

Suspension preheater-equipped cement plants are dry process plants, and therefore, have no process water discharge. Typically, suspension preheater-equipped plants operate with a total dust return to the clinkering step, and therefore have no problem with disposal of waste kiln dust. Occasionally, to meet alkali specifications in the finished cement, preheater kilns are operated with a bypass of some of the kiln exit gases. The dust collected from this bypass is discarded, since it is high in alkali content, and thereby provides an alkali purge stream from the process. The quantities of particulates and SO_2 from a suspension preheater kiln are well known and present no more problems in either magnitude or nature than those with which the cement industry is already familiar.

If waste kiln dust from a suspension preheater bypass system is discarded, its physico-chemical nature should lie within the range of characteristics of kiln dust from cement plants now operating in the United States. Therefore, the rain water run-off and leaching problems associated with the disposal of waste kiln dust from such a system should also be no different than those associated with the disposal of kiln dust from plants now operating.

2. Flash Calciner

This is a significant new variation of the suspension-preheater rotary kiln which has gained wide acceptance in Japan and Europe. The first commercial installation in the United States is nearing completion. Since the flash calciner is a dry process, the same observations and comments we made on the suspension preheater are applicable. Approximately 50% of the total fuel required for the clinker production step is burned at a relatively low temperature, with a low percent excess combustion air and quite uniform combustion gas composition throughout the combustion chamber. It has been reported that these characteristics are responsible for the NO_x produced by a flash-calciner-equipped kiln being significantly lower than for either the suspension preheater or long rotary kiln.

The particulates and SO_2 emissions from the flash-calciner-equipped rotary kiln are expected to be approximately the same as those from a suspension preheater, except when part or all of the rotary kiln combustion gas bypasses the flash-calciner and suspension-preheater vessels in order to produce low alkali cement. Although no data are available on the efficiency of the collection within the rotary kiln of SO_2 by its chemical reaction with the calcined, cement-making raw materials fed from a flash calciner to form calcium, potassium, and sodium sulfates, the efficiency is expected to be quite high. Therefore, there is a possibility that the SO_2 emissions from a partial or total bypass system may be in conflict with air pollution regulations.

3. Fluidized-Bed Cement Process

The fluidized-bed cement process utilizes a fluidized-bed reactor, rather than a rotary kiln, for the production of portland cement clinker. Although no commercial plant has yet been built using the fluidized-bed clinkering reactor, a semi-commercial-scale plant of 100-ton-per-day (tpd) capacity was built and operated successfully for a period of several years.

The reported data indicate that the combustion gases leaving the fluidized-bed reactor are as low in SO_2 as those of a rotary kiln and are significantly lower in particulates and NO_x. In fact, the particulates consist almost entirely of water-soluble potassium and sodium sulfates. This suggests that these particulates, when collected, could prove to be a valuable byproduct, or intermediate product. The fluidized-bed cement process is a dry process, and therefore has none of the process water effluent which is common to the conventional wet process plant.

This process, offered by two U.S. firms to the cement industry, employs the generation of steam as one mode of process heat recovery and is reported to be equivalent in overall thermal efficiency to the suspension preheater-equipped rotary kiln, which exhibits the highest thermal efficiency (and consequently the lowest Btu consumption per ton of cement produced) of any of the available rotary kiln-type cement clinkering process alternatives.

All other things, such as the chemical and physical characteristics of the raw material, being constant, the fluidized-bed clinkering reactor will produce cement clinker of significantly lower alkali concentration than any of the rotary-kiln-type clinkering processes. This results from the significantly higher alkali volatilization in the fluidized-bed reactor and the indirect means of heat recuperation from the hot combustion gases exiting the reactor compared with the direct heat recuperation by raw material particles in the rotary-kiln types of clinkering process alternatives.

Therefore, most of the particulates contained in the combustion gases leaving the fluidized-bed reactor are quite different from those from any of the rotary kiln-type processes. Approximately 97% are water-soluble potassium and sodium sulfate, and the remaining 3% are finished clinker particles. Also, since the extent of alkali volatilization in the fluidized-bed process is significantly greater than in the rotary kiln-type clinkering process, the quantity of alkali sulfate emitted in the effluent combustion gas stream will be significantly higher than in a comparable rotary kiln-type clinkering process, maybe two or three times higher. Since most of these particulates are alkali sulfates which have been volatilized from the clinkering raw materials, they are expected to be extremely fine and are more appropriately defined as a fume. Although no specific data are reported concerning the operation of such a collection device, glass cloth filters should suitably collect these particulates. The total pounds of particulates emitted per ton of cement clinker produced is expected to be considerably less than from any of the rotary kiln-type clinkering processes. This should be a significant benefit of this process in the discarding of alternative disposal of the particulates, especially if these alkali sulfates have a value as a chemical raw material or plant nutrient, for example.

Actual data obtained from the operation of a pilot-scale fluidized-bed cement reactor show that the NO_x concentration in the combustion gases is significantly less than from an equivalent rotary kiln process. The reasons for this are that the fluidized-bed reactor operates at a lower temperature and the fuel in the fluidized-bed reactor can be burned with only a very small quantity of excess air. Also, the high heat and mass transfer rates which are exhibited by fluidized beds reduce oxygen concentration gradients within the gas phase to very low levels.

4. Conversion to Coal from Natural Gas and Oil

Although this is not a process change per se, as a change to a lower value fuel, it is within the scope of our study. Until recently, 45% of the cement produced in the United States came from cement plants using natural gas as fuel and 15% from plants using oil. Approximately 40% of cement was produced using coal fuel. Pulverized coal can be successfully burned as the fuel in any of the current rotary kiln cement installations in the United States. It appears that industry is presently converting its kiln-firing systems to coal. The two main environmental consequences of switching from natural gas or oil to coal are:

- Fugitive particulate emissions and rainwater run-off which come from the storage and handling of coal and

- The presence of coal fly ash in kiln dust which is wasted or discarded.

Coal-fired steam electric generating facilities handle and store large quantities of coal. The equipment and handling techniques used by these utilities should prove equally satisfactory for the control of fugitive emissions which will attend the use of coal in cement plants. The presence of coal fly ash in the kiln dust will increase the number of elements, and possibly their concentration in the dust. However, this does not appear to be in potential conflict with any environmental regulations.

C. ADDITIONAL RESEARCH

During this study, we identified several areas in which additional data or information would have been helpful. This forms the basis of our recommendations for additional research into current or future processes and industry practices in the United States portland cement industry, i.e.:

(1) Develop and implement a program to sample and analyze dust from various kiln systems, especially those burning coal, in order to correlate the trace elements, especially the heavy metals in the dust wasted, with the presence of those elements or constituents in the raw materials and coal burned.

(2) Develop and implement a test program at a number of cement plants with clinkering facilities employing long-rotary-kiln, suspension preheater, or flash-calciner processes burning coal as the fuel.

Coal of various sulfur levels should be tested to determine the effect on operation of the level and nature of sulfur in gas, dust, and clinker. The benefits which derive from the physical and/or chemical cleaning of coal to reduce pyritic sulfur levels in coal for cement manufacturing could also be quantified.

(3) Develop and implement a program to analyze and study ways of using waste kiln dust (for example, as a soil conditioner or plant nutrient, or as the primary or major raw material feed component to the fluidized-bed cement process).

(4) Develop and implement a commercial-scale test program on one or more flash-calciner-equipped rotary-kiln cement-making facilities to characterize the gaseous and particulate emissions. Of particular interest would be the emissions from operating with a bypass of a considerable amount of the combustion gases to eliminate alkalies.

III. INDUSTRY OVERVIEW*

In 1974, 53 companies in 41 states and Puerto Rico produced more than 79 million short tons of cement, which brought about $2.1 billion in net sales. Of all the hydraulic cement products shipped, more than 90% was portland cement; the remainder was masonry, natural, or pozzolanic cement.

In general, cement companies market locally, where they may compete with as many as 15 to 20 other companies. Currently, all but 10 states have one or more cement plants. Some companies have as many as 14 plants. Since cement has a high weight-to-value ratio, it is generally transported on land by rail or truck over a radius of 200-300 miles surrounding the cement plant. For companies with access to water transportation, market areas are extended considerably beyond this radius. Distribution terminals are a vital part of cement marketing and transportation. Corresponding with the increase in excess capacity that started about 1959, the number of distribution terminals increased rapidly. By 1964, 164 new terminals, which accounted for more than 20% of all direct shipments to customers, had been built. This change reflected the intensified efforts of cement producers to hold or increase sales by being able to provide faster service.

One method of lowering distribution costs for cement distribution is to increase the use of water transportation. Three major cement-consuming areas where water transportation is possible are: (1) the East Coast and the Hudson River, (2) along the Great Lakes, and (3) along the Mississippi River. The plants in these areas are among the largest in operation.

Plant age is difficult to define since a single plant often has major processing equipment with different ages. In the cement industry, 168 plants operate 434 kilns, the major piece of equipment. Almost half (47%) the kilns now operating have been built since 1955. They provide 68% of the total cement-producing capacity.

A major factor in determining plant size is the cost of distribution from a plant location. This cost depends on the demand centers which the plant might supply, the distances involved, and the types of transportation to which the plant would have access. Larger and fewer kilns per plant offer several cost-saving opportunities, relating to fuel economies, labor economies, quality control, and ease of automation.

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*See Appendix A for supporting data.

Among world producers of hydraulic cement, the United States ranks third. In 1973, the United States produced 11% of the total world production. While world production of hydraulic cement has grown at 7.9% per year, U.S. production has grown at 2.0% per year.

Cement is manufactured via two processes. In the dry process the raw materials are dried before being ground and blended; in the wet process, water is added to the raw materials, which are then ground wet. Although more than half of all cement was produced by the wet process in 1974, this fraction has been declining since 1968. The dry process production has grown to 32.8 million short tons of cement clinker in 1974. This growth was largely a result of increased fuel prices, since the dry process consumes less energy. Despite its position as one of the world's largest cement producers, the United States has been importing cement and clinker at an increasing rate during the last ten years. Imports in 1974 totaled 5.7 million short tons. The major source of imports is Canada, which contributes 39% of all imports, followed by the Bahamas with 14%, Norway with 12%, and the United Kingdom with 11%.

Imports in 1974 declined 14% from the peak level of 6.6 million short tons in 1973. Various factors, such as decreasing domestic demand and increased prices of imports, affected the decline. Bulk clinker is contributing an increasing percentage to the total cement imports.

Cement is sold primarily to ready-mix concrete producers who subsequently sell concrete to various contractors. In 1974, ready-mix concrete producers consumed 66% of the total cement shipped by domestic producers. The next largest consumer, concrete product manufacturers, used 14% of the total shipped to make concrete block and pipe and precast, prestressed concrete, among other products.

Because of the relatively high level of fixed costs associated with cement production, the industry's rate of capacity utilization correlates closely with profitability. The 1950's were profitable years for the cement industry. When the rate of utilization peaked at 94% in 1955, the highest rate of return, 18.6%, was achieved. This profit rate was 25% above the profit rate of all manufacturing companies for that year.

Attracted by the high profits of the 1950's, established firms expanded capacity, but capacity expanded far more rapidly than demand. Between 1950 and 1968, production rose 74% from 43 to almost 75 million short tons, while capacity rose 100% to its peak level of almost 96 million short tons in 1968.

From 1970 to 1972, the cement industry operated at nearly 90% of its capacity--the spread between supply and demand was narrowed to the point where a definite shortage existed. By 1974, demand declined due to depressed housing construction activity, increased inflation, and an uncertain national economy.

Faced with the prospect of continued low returns, a growing number of what were once predominantly cement firms began to diversify. Vertical integration with cement's leading market, ready-mixed concrete producers, is relatively new. Before 1956, only 2 cement companies operated ready-mixed concrete facilities; by March 1966, the number had grown to 19.

In addition to integrating vertically, cement companies have: (1) integrated horizontally with other cement producers in the same market area, (2) merged with firms to extend market areas, and (3) merged with non-cement companies to extend product lines. Most of the acquisitions were market-extension mergers.

Largely due to consolidations and acquisitions, the number of cement companies has been declining steadily, going from 94 in 1923 to 51 in 1974. No single company accounts for more than 7.5% of the total cement production. While the four largest firms account for nearly 24% of the total capacity, they are contributing smaller percentages of the total capacity than they did in either 1950 or 1964.

Though no cement company serves the entire United States, the largest firms cover major portions of the country by operating numerous plants. For example, the four leading firms operate an average of 11 plants.

IV. ALTERNATIVE PROCESSES

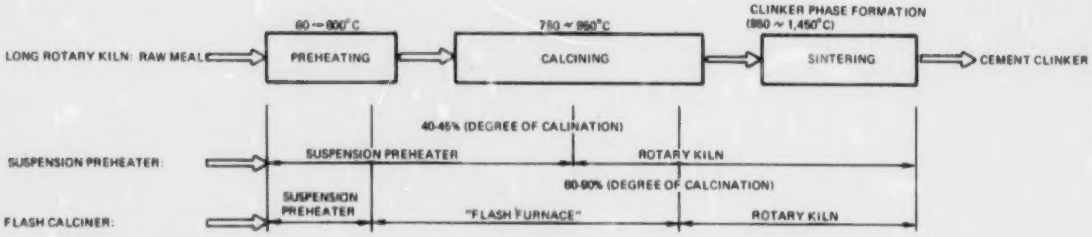
A. SUSPENSION PREHEATER

1. Process Description

A portland cement rotary kiln consists of essentially three separate zones (Figure IV-1). The three zones, based on the temperature range, and the nature of the physical and/or chemical changes or reactions which occur within them, are:

- preheating
- calcining
- sintering (or clinkering)

Comparing the three zones for the conventional long rotary kiln versus those for a rotary kiln using a suspension preheater and a flash calciner (Figure IV-1), we see that there is no sharp demarcation between adjacent zones in the rotary cement kiln. However, the temperature profile and the chemical composition of the raw materials in the kiln show approximately where the zones are (Table IV-1).


LONG ROTARY KILN: RAW MEAL
60 ~ 800°C
PREHEATING
750 ~ 950°C
CALCINING
CLINKER PHASE FORMATION
(950 ~ 1,450°C)
SINTERING
CEMENT CLINKER
40-45% (DEGREE OF CALINATION)
SUSPENSION PREHEATER:
SUSPENSION PREHEATER
ROTARY KILN
80-90% (DEGREE OF CALCINATION)
FLASH CALCINER:
SUSPENSION PREHEATER
"FLASH FURNACE"
ROTARY KILN

Source: Seki, M. et al, (1974) (IEEE, 1974 Cement Industry Technical Conference, Mexico City)

Figure IV-1. Schematic Diagram of the Cement Clinker Burning Process

TABLE IV-1

CHEMICAL ANALYSES OF RAW MEAL, ASH, CLINKER AND DUST FOR LONG WET-PROCESS KILN

No.	constituents	raw meal		ash	clinker		dust in clean gas		precipitated dust	
			ignited			ignited		ignited		ignited
		a	b	c	d	e	f	g	h	i
1	insoluble residue	-	-	-	0.08	0.08	-	-	-	-
2	SiO_2	12.26	19.39	37.43	20.19	20.22	16.90	21.06	16.10	20.17
3	Al_2O_3	4.30	6.80	20.41	6.63	6.64	5.09	6.34	6.33	7.93
4	TiO_2	-	-	-	0.20	0.20	0.21	0.26	0.22	0.28
5	P_2O_3	-	-	traces	-	-	-	-	-	-
6	Fe_2O_3	1.45	2.29	28.96	3.75	3.76	13.28	16.55	5.24	6.57
7	Mn_2O_3	-	-	-	0.20	0.20	-	-	-	-
8	CaO	43.93	69.49	4.14	64.50	64.60	16.58	20.66	35.87	44.95
9	MgO	0.61	0.97	1.75	0.98	0.98	0.72	0.90	0.57	0.71
10	SO_3 total	0.13	0.20	3.21	1.89	1.89	15.54	19.37	7.86	9.85
11	S	-	-	-	0.00	0.00	-	-	-	-
12	K_2O	0.67	1.06	3.40	1.07	1.07	9.60	11.96	6.70	8.39
13	Na_2O	0.091	0.14	0.18	0.087	0.087	1.70	2.12	0.35	0.44
14	loss on ignition	36.78	-	-	0.16	-	19.75	-	20.20	
15	sum 1-14	100.22	100.33	99.48	99.74	99.73	99.37	99.22	99.44	99.29
16	non-volatile oxidic components= sum 1-9	62.55	-	92.69	96.53	-	52.78	-	98.60	-
17	C	0.07	0.17	-	-	-	-	-	-	-
18	CaO free	-	-	-	1.02	1.02	-	-	0.93	1.16
19	CO_2	33.64	-	-	-	-	-	-	-	-
20	H_2O (<100°C)	39.2	-	-	-	-	-	-	-	-
21	H_2O (>100°C)	3.14		-	-	-	-	-	-	-

Source: Weber, P., "Heat Transfer in Rotary Kilns", Zement-Kalk-Gips, Special Edition, 1973

a. Preheating Zone

Essentially no chemical reactions occur in this zone. The raw material is completely dried of moisture and its temperature progressively increases as heat is transferred to the feed material from the hot combustion gases passing countercurrent to the raw material flow as they exit the cold feed end of the rotary kiln. This heat is transferred by conduction and convection between the gas and the raw material, and also between the hot refractory brick or castable refractory lining (of the inner surface of the kiln) in the raw material. The refractory lining of the kiln in the preheating zone is heated by the hot combustion gases; since the rotary kiln is turning on its longitudinal axis, the hot refractories turn under the bed of raw material, and thereby transfer heat into the bottom of the bed by conduction. During its passage through this preheated zone, the cold raw material feed is heated to approximately 1400°F.

b. Calcining Zone

The interface between the preheating and the calcining zone is not a physical one within the rotary kiln proper, but is marked by the onset of significant thermal decomposition of the calcium carbonate in the raw material, which constitutes approximately 75% of the raw feed. This thermal decomposition, or calcination, with consequent liberation of carbon dioxide, is the first major chemical reaction which occurs, and is the precursor of a complex series of solid-solid and solid-liquid reactions which are responsible for the ultimate production of the four main portland cement compounds.

c. Clinkering Zone

After the calcium carbonate has essentially finished decomposing to calcium oxide and carbon dioxide (the latter carried out of the kiln by the combustion gases), a series of reactions between the calcium oxide and the other components of the raw material ultimately results in the formation of the four major portland cement compounds:

- tricalcium silicate (C_3S)*
- dicalcium silicate (C_2S)
- tricalcium aluminate (C_3A)
- tetracalcium alumino-ferrite (C_4AF)

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*$C = CaO$, $A = Al_2O_3$, $S = S_1O_2$, $F = Fe_2O_3$

The formation of these major cement compounds is an exothermic reaction which liberates a sizeable quantity of heat in the sintering (clinkering) zone. This process generates a sufficient liquid phase for the reacting materials to consolidate to clinker in the form of dense solid modules which range in size from approximately one-half inch to three inches.

2. Definition

A suspension preheater is a modification to, or an addition to, a cement rotary kiln. It is attached to the raw feed inlet end of the kiln, totally replacing the preheating zone of the rotary kiln. The preheater is an assemblage of refractory-lined steel ducts and vessels in which the hot gases leaving the calcining zone of the rotary kiln contact the incoming cold raw feed. This is accomplished by mixing the raw feed into the hot combustion gases flowing at high velocity through the ducts and vessels. The raw material particles are entrained by the hot gases, resulting in a cloud of raw material particles carried by the hot gases. This cloud consists of a uniform dispersion of raw feed particles in intimate contact with the hot combustion gases. Suspension preheating achieves heat transfer characteristics - both rate and amount - from the hot combustion gases which greatly exceed those of the simple preheating zone of the conventional cement rotary kiln.

Since the suspension preheater actually replaces the preheating zone of a cement rotary kiln, it can result in a significant shortening of the rotary kiln. If an operating, dry-process rotary cement kiln is converted to a suspension preheater kiln, approximately one-half of two-thirds of the original rotary kiln can be discarded.

In addition to preheating raw material, the suspension preheater also accomplishes a considerable amount of raw material calcination. Typical suspension preheaters heat cold raw feed to approximately 1400°F, and accomplish 30-40% of the total calcination, or thermal decomposition of the calcium carbonate, the main component of the raw feed. Consequently, the rotary kiln receives hot and partially calcined raw material.

There are several variations of the suspension preheater[*] (Figure IV-3); however, the process concept can be illustrated by the four-stage Humbolt suspension preheater (Figures IV-2 and IV-3). The key element of this preheater is the combination of a vertical section of ducting with a relatively small cross-sectional area. The hot combustion gases from the rotary kiln flow up through this duct, which is refractory-lined to protect the steel from the high-temperature gases and from abrasion of the solids carried by those gases. Raw feed is dispersed in the hot gases near the bottom of the duct. This results in a cloud of fine particles within the high-velocity, upward-moving stream of hot combustion gases.

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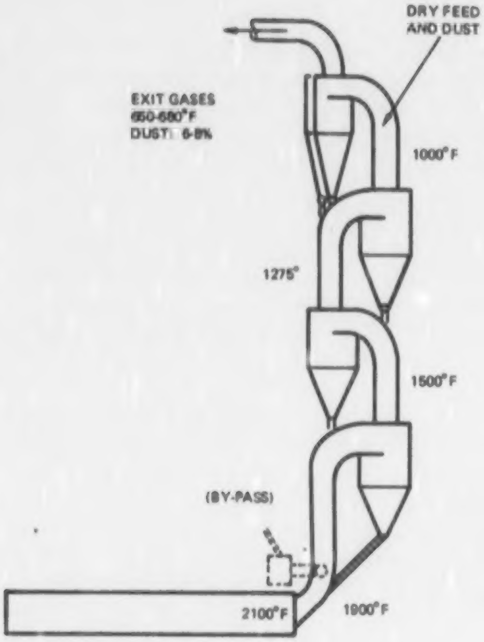
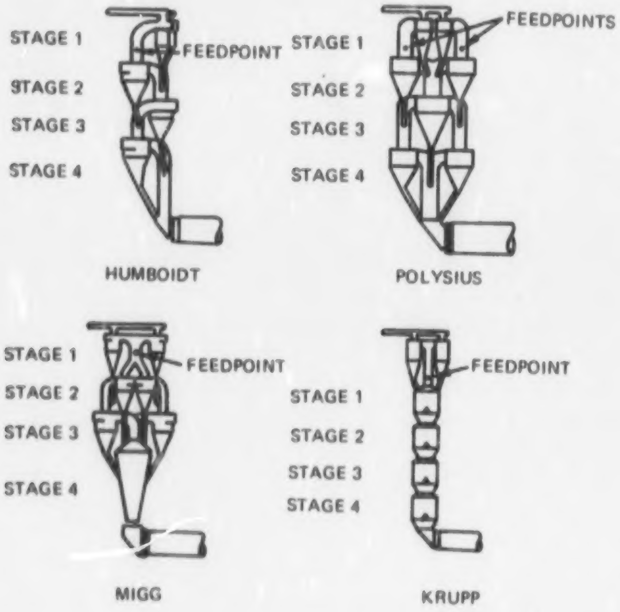
[*] Further details on preheaters as well as other process options discussed can be obtained from the references accompanying the Figures.


DRY FEED
AND DUST
EXIT GASES
650-680°F
DUST: 6-8%
1000°F
1275°
1500°F
(BY-PASS)
2100°F
1900°F

Source: Norbom, H.R. I.E.E.E. Cement Technical Conference, Miami, Florida, May 1973.

Figure IV-2. Schematic Diagram of a Typical Four-Stage Suspension Preheater


STAGE 1
FEEDPOINT
STAGE 2
STAGE 3
STAGE 4
HUMBOIDT
STAGE 1
FEEDPOINTS
STAGE 2
STAGE 3
STAGE 4
POLYSIUS
STAGE 1
FEEDPOINT
STAGE 2
STAGE 3
STAGE 4
MIGG
FEEDPOINT
STAGE 1
STAGE 2
STAGE 3
STAGE 4
KRUPP

Source: Garrett, H.M. and J.A. Murray – Rock Products, p. 58, August 1974.

Figure IV-3. Representative Four-Stage Suspension Preheater Systems Presently Being Offered by the Machinery Industry

Because of the very small size of the raw feed particles and the excellent gas/solid contact, the temperature difference between the solids and the gas is equilibrated within a fraction of a second. The final feed preheat temperature is primarily a function of the ratio of the mass flow rate of solids and combustion gases.

After the solid particles have extracted the useable heat from the combustion gas stream, the hot feed particles are recovered from that gas stream. The Humboldt suspension preheater uses a cyclone to accomplish this. The vertical duct section carrying dust-laden gases makes a 90° bend and tangentially enters a cyclone. The steel cyclone is refractory-lined for temperature- and abrasion-resistance. The solids discharge from the bottom of the cyclone, and the gas stream exits through the top center of the cyclone.

What has been described thus far is a single-stage suspension preheater, which is a commercial variation of the more common four-stage suspension preheater, and some of these have recently been installed in North America. The advantage of such a single-stage suspension preheater over the more common four-stage form is that the single-stage unit recuperates a significant amount of heat from the hot combustion gases for a minimum of fixed capital investment, and has less operating and maintenance costs than the four-stage units.

A four-stage suspension preheater consists of four of these duct/cyclone unit elements assembled in series. This then provides four separate countercurrent heat transfer stages with greater thermal efficiency than the single-stage preheater.

When the duct/cyclone unit representing a single-stage suspension preheater is expanded into a series of four separate stages, the resulting preheater looks like those shown in Figure IV-3.

Stage one, which is located at the top of the unit, consists of two cyclones in parallel. This provides higher velocities within these cyclones which generate higher dust collection efficiency and minimize the amount of raw feed carried to the subsequent dust collector. The raw feed enters the main vertical duct, which makes a 90° bend, and is divided into two streams, each of which passes into one of the two first-stage cyclones. The combustion gas temperature at this point is quite low. The partially preheated raw feed solids collected by both of the cyclones in the first-stage exit through the bottom of these vessels and drop into the gas stream leaving the third-stage cyclone. This duct is the gas inlet to the second-stage cyclone. This process is repeated four times, with the final preheated raw material, partially calcined, and at about 1400°F, passing down into the feed end of the rotary kiln.

3. United States Situation

In the last few years, there has been a significant renewal of interest in the suspension preheater in the United States. The design and operation of the suspension preheater for the United States has evolved along lines which permit the manufacture of lower-alkali cement clinker and a reduction in the operating problems due to sticking or clogging of the preheater system, which is due in part to the presence of alkalies.

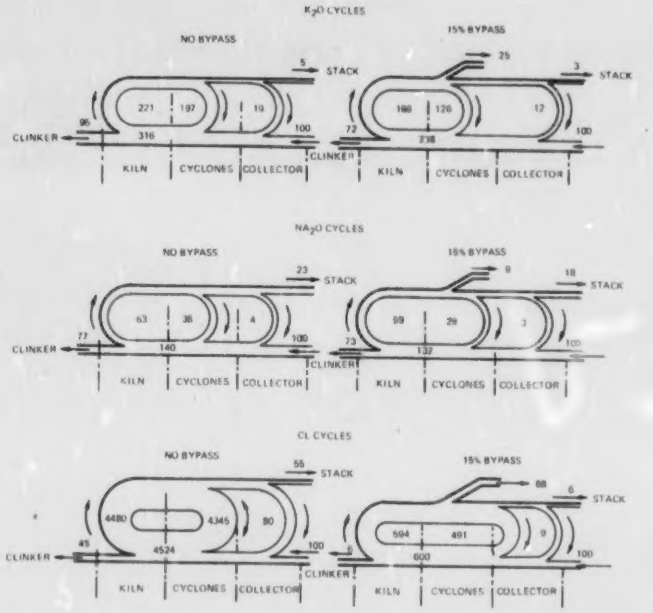
One of the key developments specifically for the reduction of the alkali content in clinker, which also tends to diminish the problem of raw material sticking in the lower stages of the suspension preheater, is the incorporation of a bypass between the rotary kiln and the suspension preheater. This permits the direct removal of some of the combustion gases leaving the rotary kiln, bypassing some of the combustion gases from the kiln around the preheater. This produces an effective outlet for alkalies, sulfur and any chlorine present, since the combustion gases at this point in the system usually contain the highest concentration of these recirculating materials. The heat efficiency is diminished somewhat through the use of such a bypass. Compared to the long wet-process and the dry-process rotary kiln systems, the thermal efficiency of a four-stage suspension preheater with sufficient gas bypass for use in the United States is still quite attractive because of the reduction in fixed capital investment and in fuel required.

Figure IV-4 shows the alkali, chloride, and sulfur cycles in a four-stage Humboldt-type suspension preheater, both with and without a bypass. For the case with bypass, 15% of the combustion gas is bypassed. The diagrams show the actual flow of the alkalies and chlorine. The width of each line is proportional to the flow rate. For each case, 100 parts of the species being considered enter with the raw material feed, and the numbers on the figures indicate the quantity of these species in their recirculation through various parts of the preheater kiln system.

4. Current Applications

There is a strong trend in the U.S. cement industry toward the application of the suspension preheater (Tables IV-2 and IV-3). Several of these installations are new facilities, such as Gifford Hill & Company's Harleyville, S.C., facility. Recently, there have been some modifications of older wet-process cement plants to dry process through the conversion of an existing long kiln to a suspension preheater. It appears that a logical series of conversions and additions at an old wet-process cement plant with several relatively small kilns would be as follows:

- Convert the old wet-process rotary kiln to a four-stage suspension preheater. This would be done by cutting the kiln approximately in half and removing the feed end. The suspension preheater tower would be constructed adjacent to the longitudinal axis of the rotary kiln, allowing for the construction of a second preheater tower adjacent to the first, and on the other side of the kiln axis, thereby providing symmetry in plan view. The purpose of this offset



Source: Norbom, H.R., I.E.E.E. Cement Technical Conference, Miami, Florida, May 1973.

Figure IV-4. Alkali and Chloride Cycles in Four-Stage Suspension Preheater Kiln

TABLE IV-2

HISTORY OF U.S. SALES OF FOUR-STAGE SUSPENSION PREHEATERS, 1953-1973

No. & Mfg*		Year Sold	Company	Location	Remark
1	F	1953	National Gypsum	Evansville, Pa.	Shutdown approx 1966 and replaced with 2 long dry kilns. Restarted 1973.
1	F	1954	Alpha	Cementon, N.Y.	Shutdown approx 1964 and replaced with 1 wet kiln.
1	F	1954	Lehigh	Fogelsville, Pa.	Shutdown plant in 1970.
1	F	1954	Marquette	Hagerstown, Md.	Shutdown approx 1970 & replaced with one long dry kiln.
2	F	1955	National Gypsum	Alpena, Mich.	Shutdown approx 1969 & removed approx 1972.
1	F	1955	Coplay	Nazareth, Pa.	In operation.
3	F	1955	Medusa	Dixon, Ill.	In operation.
1	F	1955	Whitehall	Cementon, Pa.	In operation.
2	F	1955	Ideal	Boettcher, Col.	In operation with modified feed to reduce combustibles.
13	Subtotal				
1	F	1959	Alpha	Cementon, N.Y.	Shutdown approx 1964 & replaced with 1 long kiln.
1	F	1963	Whitehall	Cementon, Pa.	In operation.
1	FLS	1970	American	Oahu, Hawaii	In operation.
3	K	1970	Lonestar	Maryneal, Tex.	In operation-Modification of existing rotary kilns.
1	F	1971	Monarch	Humbolt, Kan.	In operation.
1	AC	1971	California Portland	Rillito, Ariz.	In operation.
1	AC	1971	Flintkote	Glens Falls, N.Y.	In operation.
1	F	1972	Centex	La Salle, Ill.	Under construction.
1	F	1972	Southwestern	Fairborn, Ohio	Under construction.
1	F	1972	Gifford-Hill	Harteville, S.C.	Under construction.
1	F	1972	Medusa	Clinchfield, Ga.	Under construction.
2	F	1972	Universal Atlas	Buffington, Ind.	Under construction.
1	F	1973	Monarch	Humboldt, Kan.	In design.
1	AC	1973	Flintkote	Kosmosdale, Ky.	In design.
1	F	1973	Whitehall	Cementon, Pa.	In design.
1	FLS	1973	Missouri Portland	Joppa, Mo.	In design.
1	F	1973	Capital	San Antonio, Tex.	In design.
1	F	1973	Universal Atlas	Leeds, Ala.	In design.
1	F	1973	Kaiser	San Antonio, Tex.	In design.
35	Total				

Note: Excludes five 2-stage SP units by F.L. Smidth in 1959-60 for American Cement at Oahu, Hawaii (1); Oro Grande, California (2); Clarkdale, Arizona (2).

* Legend:				
	F	Fuller Company	AC	Allis Chalmers
	FLS	F.L. Smidth	K	Krupp

Source: Garrett, H.M. and J.A. Murray, Rock Products, p. 58, August 1974

TABLE IV-3

WORLD AND U.S. DATA ON SUSPENSION PREHEATER KILNS

Developer & Manufacturer	United States Representative	Year Developed	World Sales to 1966	World Sales to 1971	United States Sales Through 1971
Humboldt[1] Germany	Fuller	1950	180	267	16
Wedag Germany		1962	15	Incl. Above	0
F.L. Smidth Denmark	F.L. Smidth	1955	24	75	1[2]
Polysius Germany	Polysius	1958	55	132	0
Krupp[3] Germany	Krupp	1964	11	26	3
MIAC Germany	Allis-Chalmers	1968	0	5	2
TOTAL			285	505	22

1) Humboldt purchased Wedag about 1969

2) Excludes 2-stage SP systems sold in United States

3) Krupp purchased Polysius about 1970

Source: Garrett, H.M. and J.A. Murray, 1974

preheater tower is for the addition of a second preheater at a future stage of capacity expansion. The major impact of this first step conversion to a four-stage suspension preheater kiln is the significant reduction in fuel energy. Where the older and relatively small wet-process kiln may have been operating with a fuel consumption on the order of 6 x 10^6 Btu/ton, the new four-stage preheater kiln should have a fuel requirement of approximately 3 x 10^6 Btu/ton; this reduction of fuel consumption by 50% provides high motivation for such a conversion. In addition, there will be a modest increase, 20-30%, in the production capacity of the kiln.

- Add a flash-calcining vessel. In this second step, the flash calciner is added between the rotary kiln and the four-stage suspension preheater. The design of the suspension preheater should allow room for this flash-calcining vessel. The flash calciner would increase the production capacity of the total facility by about 25%, and should again slightly decrease the quantity of fuel required for clinker production. This increase in capacity results from the combustion of part of the required fuel in the flash calcining vessel, and not within the rotary kiln; this provides almost totally calcined feed to the rotary kiln. The rotary kiln would probably be operated at a higher speed to maintain proper bed depth and residence time.

- Add a second calciner to the kiln. This third step employs the construction of the second suspension preheater and flash calciner in the space initially provided for this tower. This flash calciner and suspension preheater would be identical with the existing one, and would serve the same rotary kiln. The combustion gas leaving the rotary kiln would be divided into two streams and would be fed to the two flash calciner units operating in parallel. Half of the total raw feed to the rotary kiln will go to each flash calciner. The major effect of this third step would be essentially a doubling in kiln clinkering capacity, or a 100% increase in the capacity of the kiln with only a suspension preheater installed.

5. Development

The suspension preheater was invented in Czechoslovakia in 1933. However, this idea was not commercialized for 17 years, until Humboldt built its first commercial installation in 1950. Following Humboldt's initial commercialization in 1950, three other suspension preheaters were installed, all in Germany. Shortly thereafter, in 1953, the first commercial suspension preheater unit was built in the United States by the Fuller Company, operating at that time as the licensor of the Humboldt suspension preheater design.

The suspension preheater was quickly adopted by the portland cement community in the United States (Table IV-2) and in the other major cement-producing countries of the world, such as Germany and Japan (Table IV-3). In rapid succession, twelve more Humboldt suspension preheater units were sold in the United States by the end of 1955. All 13 plants came onstream during the 1955-1958 period. After 1955, there was a significant hiatus in the U.S. sales of Humboldt suspension preheaters because of considerable operating difficulties in the early units due to alkalies and the presence of combustible materials in the raw feed. One of the main problems, the alkalies -- i.e., potassium and sodium values -- are widespread in clays, shales, and other argillaceous materials, the second most important raw feed material for making cement. During the sintering or clinkering reactions in the high-temperature zone of the cement rotary kiln, the original crystal lattice, which binds the potassium and sodium atoms, is disrupted and reforms into the portland cement compounds. During this disruption, potassium and sodium appear to volatilize as the sulfates. These vapor species form in the vicinity of the flame produced by the burning fuel.

If coal is burned, the coal ash also contributes some potassium and sodium. Coal and, to some extent, oil contribute sulfur, which goes into the formation of the potassium and sodium sulfate vapor. Any chlorine present forms some potassium and sodium chloride in chemical equilibrium with the potassium and sodium sulfates. This mixture of vapor species condenses to form a fume of very fine particle size. A fraction of these alkali compounds also condenses out on the surface of the raw material dust entrained by the combustion gases. These fine particles of highly concentrated alkali sulfates and/or chlorides leave the kiln and are collected by the fourth and third stages of the suspension preheater and are returned to the kiln with the preheated raw feed. This process sets up a large recirculation of alkali compounds within the kiln/suspension preheater system.

Due to the relatively low melting point of the mixtures of potassium, sodium and calcium sulfate, this material can become sticky and can adhere to the inner refractory-lined surfaces of the ducting, cyclones, and transfer pipes of the preheater. As these deposits accumulate, they add their own measure of insulation to the refractory lining of the preheater components, thereby permitting progressively higher temperatures, which accelerate the continuing deposition of these materials. Such a process progresses at an increasing rate until sections of the preheater actually become choked with solid material, thereby requiring shutdown and cleaning of the unit. This can become costly due to loss of cement production. It can also be dangerous because of the high temperature of the material being cleaned, since the unit is not permitted to cool even for such cleaning.

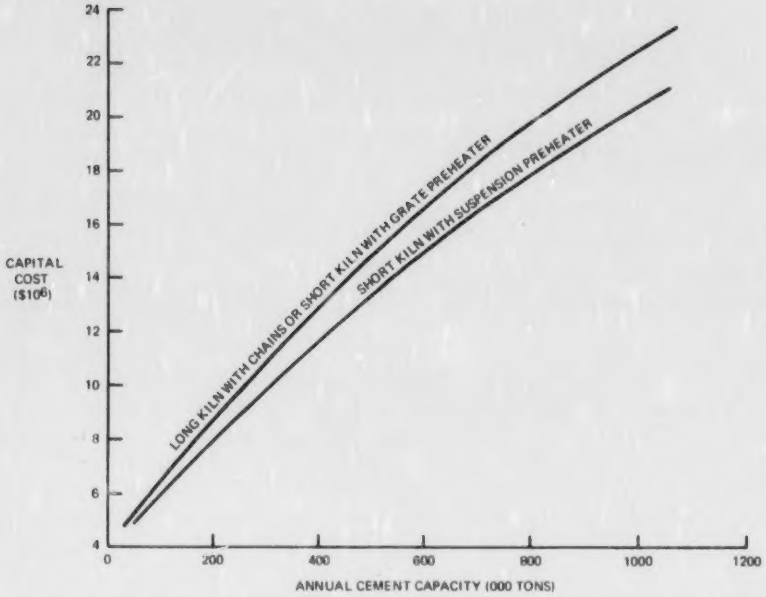
The other main problem experienced by the early suspension preheater units in the United States is caused by the presence of fuel, or combustible values, in the raw feed. In certain cement plants in the United States, the argillaceous component of the raw feed is a kerogen-containing shale, and kerogen is a combustible hydrocarbon material. These hydrocarbons are ignited when such raw feed is preheated to the 1400°F temperature found in the fourth stage of a suspension preheater. Sufficient oxygen for combustion is usually present in the combustion gases because of the excess air required to maintain proper combustion conditions in the firing end of the kiln, and air in-leakage at the rotary kiln seals. The heat liberated from this kerogen combustion within the preheater causes severe local overheating. This is accompanied by excessive calcination and reaction of the raw material components within the preheater, leading to sticky raw feed and the accumulation of hard solid deposits within the preheater and, again, requires shutdown for cleaning.

The first Humboldt suspension preheater built in the United States was at the Evansville, Pennsylvania, plant of Allentown Portland Cement Company, in 1953. Apparently this unit functioned well and there were no excessive alkali problems, nor was kerogen-containing shale a component of the cement raw material. Because acceptance of the suspension preheater in the United States was so rapid and widespread, a large number of units were built before many were tried. When the alkali and kerogen-containing shale problems were then encountered, the U.S. portland cement industry concluded that the suspension preheater was unacceptable for application to U.S. cement raw materials and this process fell into disfavor.

6. Economic Factors

a. Fixed Capital Investment

The fixed capital investment for the clinkering section of a short kiln with a four-stage suspension preheater is lower than that of a long kiln (Figure IV-5), simply because the large, heavy, refractory-lined rotary kiln is more expensive than the simpler stationary suspension preheater.



*NO COST ESCALATION CONTINGENCIES INCLUDED

Source: Margiloff, I.B. and R.F. Cascone, Rock Products Great Industry Seminar, Chicago, Dec. 8, 1975.

Figure IV-5. Total Capital Costs of Various Clinkering Sections

b. Operating Cost

The most significant difference in operating cost between the suspension preheater kiln (Table IV-4) and the conventional rotary kiln (Table IV-5) is in the unit fuel cost. (The dry-process kiln was selected for comparison because the preheater system is dry.)

In comparing the energy use between a suspension preheater system and a long conventional rotary kiln note that the electrical energy used to drive the induced draft fan that draws the combustion gases through all of the ducting and cyclone vessels of the preheater is not needed in a conventional long rotary kiln.

Furthermore, one must consider the specific raw material moisture content, grindability, type of clinker cooler used, etc. For example, raw materials containing 10% moisture may be appropriate for a wet-process cement plant but may be too moist for crushing and grinding in a dry-process plant and thus require an expensive drying step. However, the use of a suspension preheater kiln system provides a significant quantity of high-temperature gases (from the clinker cooler), not needed for combustion because of the high thermal efficiency which can be incorporated into a closed-circuit raw material grinding and drying system to handle such raw materials.

TABLE IV-4

PORTLAND CEMENT PRODUCTION COST: SUSPENSION PREHEATER/FLASH CALCINER KILN

Product: Type I Portland Cement
Byproducts: None
Annual Capacity: 445,500 tons
Annual Production: 445,500 tons

Process: Four-Stage Suspension Preheater with or without precalcining vessel
Fixed Investment: $40 x 10^6

Working Capital: $2.8 x 10^6
Stream Days/Yr: 330
Location: U.S. East Coast

	Units	Quantity/Ton	Unit Cost	$/Ton
VARIABLE COSTS				
Raw Materials: Limestone		included in other costs		
Argillaceous Components		included in other costs		
Gypsum & Minor Additives				1.00
Purchased Energy: Fuel (oil)	10^6 Btu	2.8	2.00	5.60
Electric Power	kWh	130	0.02	2.60
Water: Cooling	10^3 gal	0.45	0.03	0.01
Operating Labor	man-hr	0.6	6.00	3.60
Labor Overhead		30% of Operating Labor		1.08
Operating, Main. & Repair Supplies		2% of Plant Cost		1.80
FIXED COSTS				
Plant Overhead		70% of Operating Labor		2.52
Taxes & Insurance		2% of Plant Cost		1.80
Depreciation		20 year, straight line		4.49
TOTAL PRODUCTION COST				24.50
Pre-Tax Return on Investment		20%		19.21
TOTAL				43.71

Source: Arthur D. Little, Inc. estimate.

TABLE IV-5

PORTLAND CEMENT PRODUCTION COST: LONG ROTOARY KILN (OIL-FIRED)

Product: Type I Portland Cement
Byproducts: None
Annual Capacity: 445,500 tons
Annual Production: 445,500 tons

Process: Long Rotary Kiln Dry Process
Fixed Investment: $42 x 10^6

Working Capital: $2.8 x 10^6
Stream Days/Yr : 330
Location: U.S. East Coast

	Units	Quantity/Ton	Unit Cost	$/Ton
VARIABLE COSTS				
Raw Materials: Limestone		included in other costs		
Argillaceous Components		included in other costs		
Gypsum & Minor Additives				1.00
Purchased Energy: Fuel (oil)	10^6 Btu	4.2	2.00	8.40
Electric Power	kWh	130	0.02	2.60
Water: Cooling	10^3 gal	0.45	0.03	0.01
Operating Labor	man-hr	0.6	6.00	3.60
Labor Overhead		30% of Operating Labor		1.08
Operating, Main. & Repair Supplies		2% of Plant Cost		1.89
FIXED COSTS				
Plant Overhead		70% of Operating Labor		2.52
Taxes & Insurance		2% of Plant Cost		1.89
Depreciation		20 year, straight line		4.71
TOTAL PRODUCTION COST				27.70
Pre-Tax Return on Investment		20%		20.11
TOTAL				47.81

Source: Arthur D. Little, Inc. estimate.

The electrical-energy-saving roller mill operates to its best advantage in the raw material grinding circuit when supplied with gases which are even hotter than a conventional ball mill can accept. Therefore, the roller mill is particularly well suited to inclusion in a suspension preheater circuit, thereby increasing the suspension preheater facility's capacity for handling wet raw materials. Such a roller-mill-equipped, suspension-preheater facility can accept raw materials with moisture contents as high as 15-20%. In addition, the roller mill produces cement raw feed with 15% less consumption of electrical energy than comparably sized ball mills. This adds another dimension of total energy savings to the suspension preheater system but one which does not derive directly from the suspension preheater/kiln clinkering system only.

c. Energy Requirements

Table IV-6 compares the energy requirements for a suspension-preheater-equipped rotary kiln and a long dry-process rotary kiln in new facilities.

TABLE IV-6

COMPARISON OF TYPICAL ENERGY REQUIREMENTS FOR SUSPENSION PREHEATER AND LONG KILN
(Btu/ton cement)

	Feed Preparation (quarry, crush, dry, mix feed)	Clinkering (burn, cool)	Finishing (grind, pack)	Available Energy Recovery (steam/power generation, dryer fuel savings)	Net Energy Required After Energy Recovery
Preheater, Short Kiln					
Electrical	534,000	374,000	760,000	(346,000)	1,322,000
Fuel	336,000	3,200,000	-	(300,000)	3,236,000
Total	870,000	3,574,000	760,000	(646,000)	4,558,000
Dry, Long Kiln					
Electrical	534,000	315,000	760,000	-	1,609,000
Fuel	336,000	4,600,000	-	(320,000)	4,616,000
Total	870,000	4,915,000	760,000	(320,000)	6,225,000

Source: Margiloff, I.B. and R.F. Cascone, Rock Products Cement Industry Seminar, Chicago, December 8, 1975

7. Environmental Factors

a. Air Pollution

(1) Particulates

One of the environmentally advantageous aspects of the suspension preheater is its propensity to trap the alkalies and sulfur values within the lower- and higher-temperature stages of the preheater. These alkalies remain with the cement clinker. Therefore, a four-stage suspension preheater, operating with no bypass, would send a relatively cool combustion gas stream containing solid particulate material which is physically and chemically similar to cement raw feed to the dust collecting system.

Because the dust removed from the combusion gases leaving the suspension preheater system is essentially the same as cement raw feed, all of it is returned to the preheater system. Therefore, the adoption of the suspension preheater presents no new dimensions to the collection or disposal of solid particulates.

(2) SO_x

Raw material which has been partially calcined is highly reactive with the sulfur dioxide, forming calcium sulfate. Any SO_x which might form in the combustion gases in a rotary kiln using extremely high-sulfur coal as fuel contacts the raw material so intimately that the use of a suspension preheater system should not present any sulfur dioxide emission problems.

(3) NO_x

The concentration of nitrogen oxides (NO_x) in the combustion gases from both the long rotary kiln and the preheater system will probably be equivalent because fuel is burned in the same way in both systems. However, the absolute quantity of nitrogen oxides generated per ton of cement clinker produced by the suspension preheater kiln will be less than that produced by the long kiln, since the thermal efficiency of the suspension preheater kiln is so much better than either the long wet- or dry-process kiln.

The number of pounds of nitrogen oxides generated per ton of cement clinker produced by a suspension preheater facility operating at 3×10^6 Btu per ton should be exactly half of the quantity of nitrogen oxides produced by a long kiln which is operating at 6×10^6 Btu per ton; however, the concentration of nitrogen oxides in the combustion gases leaving both of these systems should be about the same.

(4) Costs

The fixed capital and operating costs for the air pollution control systems required by two different long conventional kilns and a four-stage preheater kiln system are shown in Tables IV-7 through IV-9. The basis for these estimates is presented in Table IV-10.

TABLE IV-7

OPERATING COSTS FOR AIR POLLUTION CONTROL SYSTEM: LONG ROTARY KILN SYSTEM (DRY-PROCESS/NO INSULATION)

Production, ton/yr	470,000
Fuel Required, Btu/ton	4.2×10^6
Capital Investment, $	1,085,000
Control Device (Kiln, Dryer, Cooler)	Glass Bag Filter
Annual Operating Costs:	
Electricity (2.70×10^6 kWh/yr), $/yr	54,000
Direct Labor (14,100 hr/yr), $/yr	84,600
Maintenance Labor (7,000 hr/yr), $/yr	49,000
Plant Overhead, $/yr	133,600
Materials, $/yr	98,000
Depreciation, $/yr	54,250
Taxes and Insurance, $/yr	21,700
Return on Investment, $/yr	217,000
Total Operating Cost, $/yr	712,150
Total Operating Cost, $/ton	1.52
Energy Consumption, 10^9 Btu/yr	28.35
Energy Consumption, Btu/ton	60,400

Source: Arthur D. Little, Inc. estimate

TABLE IV-8

OPERATING COSTS FOR AIR POLLUTION CONTROL SYSTEM: LONG ROTARY KILN SYSTEM (DRY-PROCESS/INSULATED LINING)

Production, ton/yr	470,000
Fuel Required, Btu/ton	3.4×10^6
Capital Investment, $	983,000
Control Device (Kiln, Dryer, Cooler)	Glass Bag Filter
Annual Operating Costs:	
Electricity (2.33×10^6 kWh/yr), $/yr	46,600
Direct Labor (12,200 hr/yr), $/yr	73,200
Maintenance Labor (6,100 hr/yr), $/yr	42,700
Plant Overhead, $/yr	115,900
Materials, $/yr	85,400
Depreciation, $/yr	49,150
Taxes and Insurance, $/yr	19,650
Return on Investment, $/yr	196,600
Total Operating Cost, $/yr	629,200
Total Operating Cost, $/ton	1.34
Energy Consumption, 10^9 Btu/yr	24.47
Energy Consumption, Btu/ton	52,100

Source: Arthur D. Little, Inc. estimate

TABLE IV-9

OPERATING COSTS FOR AIR POLLUTION CONTROL SYSTEM: FOUR-STAGE PREHEATER KILN SYSTEM

Production, ton/yr	470,000
Fuel Required, Btu/ton	2.8×10^6
Capital Investment, $	798,000
Control Device (Kiln, Dryer, Cooler)	Glass Bag Filter
Annual Operating Costs:	
Electricity (1.74×10^6 kWh/yr), $/yr	34,850
Direct Labor (9,150 hr/yr), $/yr	54,900
Maintenance Labor (4,100 hr/yr)	28,700
Plant Overhead, $/yr	83,600
Materials, $/yr	57,400
Depreciation, $/yr	39,900
Taxes and Insurance, $/yr	16,000
Return on Investment, $/yr	159,600
Total Operating Cost, $/yr	474,950
Total Operating Cost, $/ton	1.01
Energy Consumption, 10^9 Btu/yr	18.27
Energy Consumption, Btu/ton	38,900

Source: Arthur D. Little, Inc., estimate

TABLE IV-10

BASIS FOR OPERATING COST ESTIMATES FOR AIR POLLUTION CONTROL IN CEMENT MANUFACTURING

Power Costs, $/kWh	0.02
Operating Labor (Incl. Supervision), $/hr	6.00
Maintenance Labor (Incl. Supervision), $/hr	7.00
Depreciation, years	20
Method of Depreciation	Straight Line
Taxes and Insurance	2% of Capital Investment
Return on Investment	20%
Annual Operating Hours	7,200
Plant Capacity, ton/yr	470,000
Btu/kWh	10,500

b. Water Pollution

The wastewater characteristics, necessary wastewater treatment measures, and treatment costs for cement plants employing the suspension preheater/flash calciner process are very much similar to those associated with the base case cement plant. (See Appendix C.)

It is estimated that the suspension preheater/flash calciner alternative will generate the same quantity of non-contact cooling water as the base case plant, i.e., 648,000 gallons per day (gpd) for a 1350-tpd plant.

As in the case of the base case cement plant, the suspension preheater/flash calciner alternative will produce a waste dust, which probably will be stored in large piles or holding ponds. The quantity of dust generated is expected to be substantially less than that of the base case, 60 tpd versus 140 tpd. The dust is expected to contain a slightly higher soluble fraction than that generated by the base case cement plant. Since the quantity of dust generated is less than that of the base case, for a given storage pile depth the amount of exposed area (and thus the run-off flow rate) will be proportionally decreased. It is estimated that a 1350-tpd cement plant employing the suspension preheater/flash calciner process will require a 10-year dust storage area of 4.5 acres (20-ft depth) versus 10.6 acres for the base case. As with the base case cement plant, the storage area will have to be diked and will have to have provisions for collecting run-off water and subjecting it to clarification and neutralization prior to discharge.

Due to the lower volume of run-off water to be treated, the suspension preheater/flash calciner alternative has a slightly lower wastewater treatment cost compared to the base case - $0.39/ton of cement versus $0.46/ton of cement (Table IV-11).

B. FLASH CALCINER

1. Process Description

Although the design of flash calcining systems varies (Appendix D), the main feature which characterizes the flash calciner rotary kiln is the flash calcining vessel added between a rotary kiln and a suspension preheater (Figure IV-6).

The combustion gases leaving the rotary kiln pass through the flash calcining vessel. The hot raw material leaving the bottom of Stage 3 of the suspension preheater discharges into the flash calcining vessel. Fuel is burned in the flash calcining vessel to further calcine and preheat this raw material stream. The combustion gases combined with kiln gases carry the raw material from the flash calcining vessel into Stage 4 of the suspension preheater, from which the hot and almost completely calcined raw material discharges into the rotary kiln.

The flash calciner arrangement in Figure IV-6 requires that a considerable amount of excess combustion air be used in burning the fuel in the rotary kiln so that enough air is present in the combustion gases leaving the kiln to permit combustion of the fuel in the flash calciner vessel.

TABLE IV-11

WASTEWATER TREATMENT COSTS: SUSPENSION PREHEATER/FLASH CALCINER

Basis 1350 tpd Cement Production
330 Operating Days Per Year

CAPITAL INVESTMENT - $427,000

	Annual Quantity	Cost Per Unit Quantity	Quantity Per Ton of Production	Unit Cost ($ Per Ton of Product)
VARIABLE COSTS				
Operating Labor (including overhead)	2630 man-hr	$12/hr	0.0059	0.0709
Maintenance (inc. lbr & mtls)				0.0384
Chemicals				
Sulfuric acid	6 tons	$100/ton	1.35×10^{-5}	0.0110
Electrical Power	323,100/ kWh	$0.02/ kWh	0.73	0.0146
TOTAL VARIABLE COST				0.1349
FIXED COST				
(Depreciation @ 5%)				0.0480
(Taxes & Insurance @ 2%)				0.0191
TOTAL FIXED COST				0.0671
TOTAL ANNUAL COST				0.2020
RETURN ON INVESTMENT @ 20%				0.1917
TOTAL				0.39/ton

Notes:

1) Capital investment adjusted to 1975 level (ENR Construction Cost Index = 2126)

2) Wastewater treatment includes:
   a) Non-contact cooling water thermal pollution control via spray pond
   b) Dust pile runoff containment, collection, clarification and neutralization

3) Estimates are for the specific example of a dry-process, non-leaching cement plant and are in no way intended to represent industry-wide wastewater treatment costs.

Source: Arthur D. Little, Inc. estimates

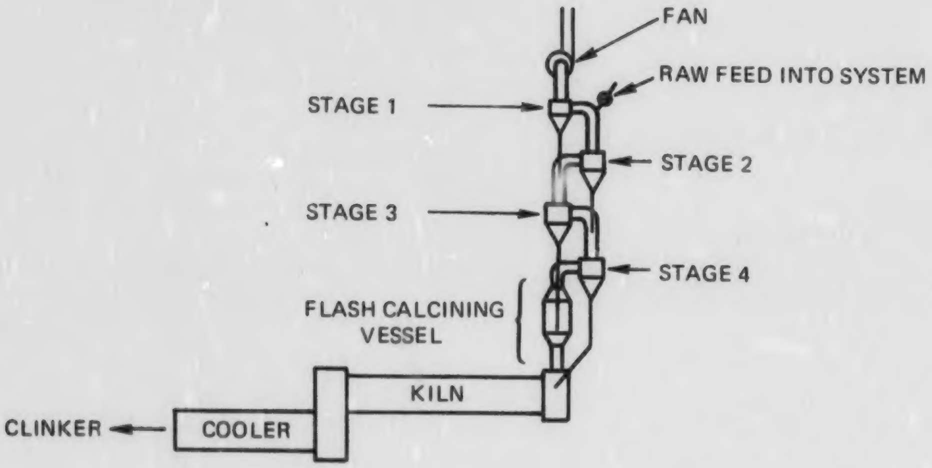


Figure IV-6. Flash Calcining System with Combustion Air for Precalciner Drawn up through Kiln

The advantages of the flash-calciner-equipped rotary cement kiln are:

- Significantly increased rotary kiln capacity. This permits very high clinker production capacities from average size rotary kilns.
- Improved kiln availability. This results from the use of conventional sized rotary kilns which exhibit refractory life considerably in excess of the large rotary kilns required for equivalent production capacities without the flash calciner.
- Reduced fuel consumption. The heat losses through the rotary kiln shell are less than those of a conventional rotary kiln. The cement produced per square foot of kiln shell area is very high.
- Reduced fixed capital investment. The flash calciner represents a slightly lower fixed capital investment than that required for the incremental amount of rotary kiln which it replaces.
- Alkali removal with less heat energy penalty than incurred by the use of a bypass in a suspension preheater kiln. Since only 40-50% of the total fuel is burned in the rotary kiln, and since the clinkering zone of the rotary kiln is the only place where the alkali compounds are volatilized, the alkali compounds are reported to be more highly concentrated in a smaller quantity of gas; therefore, bypassing less of this gas is reported to eliminate more alkalies.

- Reduced nitrogen oxide emissions. Since 50-60% of the total fuel burned in this system is burned in the flash calciner, and since the temperature of the flash calciner is maintained at only about 1500°F, the nitrogen oxides formed in this vessel are reported to be considerably less than formed in the high-temperature, free-standing flame which is burned in the rotary kiln.

- More predictable, constant and easily controlled operation. The tendency for uncontrolled periodic "rushes" within the kiln is eliminated and the function of the kiln is simplified to an extent where the prospect for truly automatic control of the whole clinkering process is much more probable with almost totally calcined raw feed than with any other clinkering system.

One of the important advantages of the flash calcining system is the very rapid calcination which takes place in the suspension flash furnace or fluidized bed vessel. By monitoring temperature, it is possible to maintain close control over the extent of calcination of the raw material, thereby providing a preheated and precalcined raw material of very uniform chemical composition to the rotary kiln. Any variations in the extent of calcination are only short-term, and the residence time and the mixing of the raw material being clinkered in the rotary kiln evens out those short-term variations. The consequence of this is a very uniform and steady rotary kiln operation and clinker product of high uniformity. This not only minimizes downtime, with consequent increase in kiln availability, but also significantly increases the prospects for the fully automated control of a rotary portland cement kiln - perhaps very soon.

Therefore, by burning a large fraction of the total fuel outside the rotary kiln, the capacity of the rotary kiln can be increased significantly, with simultaneous accrual of a host of other potential benefits: e.g., better technical performance, lower fuel energy consumption, higher-quality cement, lower costs, and reduced nitrogen oxide emissions.

2. Current Status

Several major equipment manufacturers have developed their own particular versions of the flash calciner, differing mainly in gas flow and precalcining vessel location. The following systems are now in commercial operation:

(a) Japanese

- Ishikawajima Harima Heavy Industries (IHI)
- Onoda Cement-Kawasaki Reinforced Suspension Preheater System
- Mitsubishi Fluidized Calcinator

(b) European

- Polysius System
- F. L. Smidth System

Some of these systems have been designed to use alternative fuels such as coal. (See Appendix D.) The high production capacity and the small geographic area of Japan combine to make extremely large cement plants the most economical there. The trend in Japan toward large single kilns of extremely high output has been unparalleled in the other cement-producing countries. Because the flash calciner concept has made it practical and technically feasible to operate (with high kiln availability) extremely large single-kiln facilities, the flash calciner has been adopted by the Japanese cement industry at a very rapid rate.

IHI started its research program in 1963 for the development of its version of a flash calcining system. Initial research and development work was done on a scale ranging from 2 to 20 tons per day. From there, a full-scale commercial facility with a capacity of 2200 tons per day was designed and built.

This development program solved the following problems:

- Sticking of a calcined raw material coating to the inner wall of the flash calcining furnace;
- Clogging in the preheater cyclone;
- Misfiring of the furnace-burner; and
- Coating or clogging in the rotary kiln.

At present, there are 33 flash calciner cement facilities either operating or being built in Japan. Because of the large number of installations being constructed, the Japanese equipment manufacturers who are developing and offering the flash calcining system have had an opportunity to develop their designs faster than equipment manufacturers in other countries. The IHI process became so popular that 19 plants were already sold through 1974, and 12 are now in operation in Japan. Japan is presently making 40% of its cement production with flash calcining systems, almost 60% of them using the IHI process.

The largest reported flash calciner system is at Chichibu, with a capacity of 8500 tons per day of cement clinker, and a heat consumption of less than 2.6×10^6 Btu per ton. This appears to be a record for not only the largest daily productive capacity from a single kiln facility, but also the lowest reported heat consumption.

3. Energy, Economics, and Environment

The published data on flash-calciner-equipped rotary cement kiln energy requirement, fixed capital investment, operating cost and environmental factors are reported by major types of units or for specific plants. Because of the nature of the data, we present them in this combined form for each of the five major flash calciner systems. The available data in these categories enable us to make the following general characterizations of these flash calcining systems.

a. Energy Requirements

The energy required is essentially the same or slightly less than that for a suspension preheater system. One of the reasons for this is that the capacity of the rotary kiln operating with a flash calciner system is twice that of a suspension preheater kiln. Therefore, with capacity held constant, the flash-calciner-equipped rotary kiln is significantly smaller, thereby presenting less shell area through which heat can be lost to the environment. Also, the fuel for the flash calcining vessel is burned at a low temperature, and the calcining capacity of the precalcining vessel, expressed in terms such as tons of raw feed precalcined per cubic foot (and therefore per square foot of external surface of the precalciner), is significantly greater than the precalcining or calcining zone of the rotary kiln.

b. Economics

The fixed capital investment should be slightly less than that for a suspension preheater, since a section of rather expensive rotary kiln is replaced by a stationary and smaller precalcining vessel. Except for the Mitsubishi fluid-bed precalcining system, which is the only atypical one, no data are yet available in the literature.

Operating costs are probably slightly lower than a suspension preheater only to the extent of a smaller kiln and better refractory life and possibly more stream days per year.

c. Environmental Factors

(1) Air Pollution

(a) Particulates

The quantity and dust loading of the combustion gas stream leaving a flash calciner should be essentially the same as for a comparable suspension preheater. The difference would be in the gases leaving through a bypass. However, there are no data in the available literature to clarify this.

(b) SO_x

By the time the combustion gases exit to the atmosphere, essentially all of the SO_x should be absorbed and reacted with the raw feed. However, any gases which might be bypassed could be different in SO_x content from suspension preheater bypass gases because the raw feed entering the flash calciner kiln are almost completely calcined, and also have a significantly lower kiln residence than in a suspension preheater.

(c) NO_x

NO_x is reported to be lower than from a suspension preheater or long kiln because half of the fuel being burned in the precalciner is at a low and uniform temperature and oxygen content.

(d) Costs

The fixed capital and operating costs for the air pollution control systems required by a flash calciner are essentially the same as for a suspension preheater. (See Table IV-9.)

(2) Water Pollution

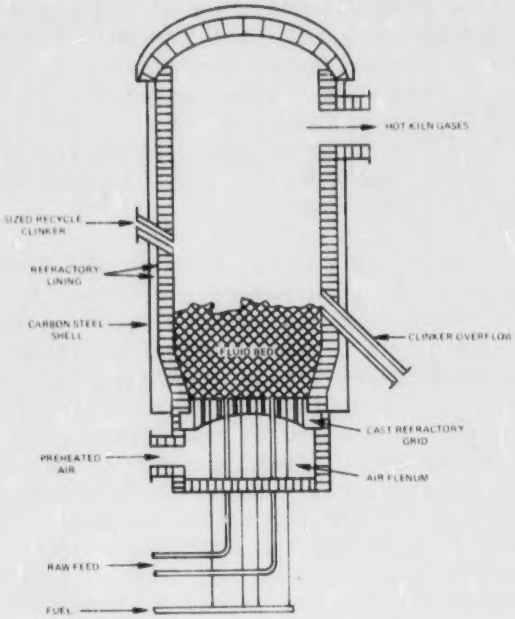
The wastewater characteristics, necessary wastewater treatment measures, and treatment costs for cement plants employing the flash-calciner-equipped rotary kiln are essentially identical with those associated with the suspension preheater. (See Section A.)

C. FLUIDIZED-BED CEMENT PROCESS

1. Process Description

The difference between the fluidized-bed cement making process and the conventional processes is in the high-temperature clinkering step. All of the other steps are essentially identical.

In a fluidized-bed reactor (Figure IV-7), the raw material is introduced at the bottom of the bed of fluidized cement clinker particles which is maintained at a temperature high enough to permit the clinkering reactions to occur. The extremely large heat transfer coefficients of the fluidized bed quickly heat the incoming raw material particles up to clinkering temperature. As these raw materials are heated and begin to chemically react, an intermediate liquid composition is reached. This permits the partially reacted liquid reactants to adhere to the surface of the individual particles of clinker, rather than be carried out of the bed by the fluidizing gases. Upon completion of the clinkering reactions, this thin liquid, or semi-solid layer, quickly solidifies.



Source: Margiloff, I.B., and R.F. Cascone, Rock Products, Current Industry Seminar, Chicago, Illinois, Dec. 8, 1975

Figure IV-7. Detail of Kiln for Scientific Design Fluid-Bed Cement Process

The new surface is itself refractory and solid at the reactor temperature. The clinker particles thus produced are spherical, and increase in diameter as successive increments of clinkering raw materials are applied to their surface. This continues as long as the clinker particles remain in the fluidized bed. The individual particles do not stick together to form larger agglomerates, but remain discrete spheres.

The bed of clinker particles is fluidized by hot combustion gases produced by the introduction of preheated combustion air through an air distribution grid which forms the floor of the reactor vessel. Fuel is metered into the bed, and burns in the continuous gas phase present between the individual particles of cement clinker. Any hydrocarbon fuel such as natural gas, oil, or coal, can be used. When operated properly, it is reported that there are no visible flames in the free space above the upper surface of the fluidized bed, and all combustion takes place in the interstices of the fluidized bed proper. The bed operates at a temperature of 2400°F.

The bed depth is apparently determined by combustion requirements. Too shallow a bed can permit fuel combustion above the surface of the bed, where the heat would not be adequate for the clinkering reactions and would also probably be hazardous to heat transfer surfaces located downstream of the reactor.

The optimum particle size distribution of the bed material (Table IV-12) is maintained in the bed by the continuous removal of bed material and the reintroduction of crushed and screened clinker product to act as nuclei for continuing growth of new particles. This extraction of bed material and recycling of the finest fraction (combined with a suitable quantity of crushed and screened fine "seed" material) permits the steady-state, continuous operation of the fluid bed reactor. This appears to be one of the key operational aspects of this process.

Figure IV-8 illustrates the recycle of both the fine fraction of extracted bed material and the finer product obtained by crushing coarse particles removed from the bed to act as new "seed" particles. The values shown on this figure illustrate a simple material balance around the reactor. This material balance demonstrates the approximate flow rate of the major streams of solid reactants, products, and recycle streams. The stream of raw feed material entering the bottom of the fluidized bed is shown to be 6000 lb. After calcination and clinkering, this material produces 4000 lb of finished portland cement clinker. Essentially all of the 2000-lb difference, or weight loss, is accounted for by the mass of carbon dioxide liberated from the raw feed material. During calcination, calcium carbonate, the main chemical constituent of portland cement raw feed material, is thermally decomposed to yield calcium oxide and carbon dioxide gas, which is carried from the reactor along with the combustion gases generated within the bed of fluidized clinker.

TABLE IV-12

OPTIMUM PARTICLE SIZE DISTRIBUTION FOR BED OF CLINKER PARTICLES

-0.3" + 4 mesh 10%

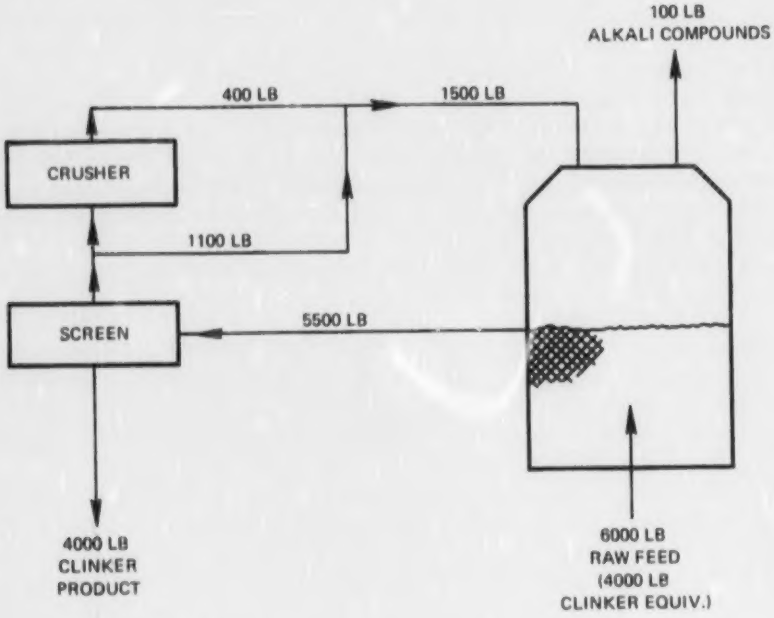
-4 mesh + 6 mesh 20%

-6 mesh + 8 mesh 35%

-8 mesh + 10 mesh 25%

-10 mesh + 20 mesh 10%

Source: Sadler, A.M., Paper presented at A.I.Ch.E., New York Meeting, Nov. 30, 1967.



Source: Sadler, A.M., A.I. Ch. E. New York meeting, Nov. 30, 1967.

Figure IV-8. Material Balance Around the Reactor

The 4000 lb of equivalent clinker generated from this raw feed stream are deposited on the surface of the particles of clinker which constitute the fluidized bed. Accordingly, the bed increases not only in mass by that amount, but also in total volume, raising the upper surface of the bed. As the surface rises, there is a consequent increase in the rate at which clinker particles spill through the overflow outlets from the reactor. Due to the well-mixed nature of the fluidized bed, the clinker particles which leave the reactor over a period of time have a particle size distribution which is the same as the average particle size distribution of the entire bed of fluidized particles.

Only the largest (diameter) particles are considered finished product. They are separated from the overflow stream of reactor material by a screening step. To remove the 4000 lb of clinker product, a total overflow of reactor contents equal to 5500 lb is screened. The 1500 lb of finest material are then returned to the reactor for further growth.

If a simple screening and recycle process were carried out, the particle size distribution of the fluidized bed would be impossible to maintain, and would progressively shift toward the larger end of the size spectrum. To maintain a constant and predetermined particle size distribution, part of the 1500 lb of recycled particles of clinker are crushed to a smaller size, to provide the nuclei necessary to maintain a steady-state operation. Of the 1500 lb of recycled material, 1100 lb are recycled directly to the reactor, while 400 lb are crushed to a finer size before being returned to the reactor.

2. Reactor

The fluidized-bed reactor is a vertical cylinder fabricated of carbon steel and lined with high-temperature refractories. The inner refractory lining would probably consist of high-temperature refractory brick and an insulating layer of refractory material would be located between that brick lining and the outer carbon steel shell. The bottom of the vessel is a cast refractory grid. This grid would contain a large number of vertical holes through which the fluidizing and combustion air would pass upward into the vessel. Also, appropriately sized pipelines for conveying cement raw feed and fuel would pass up through this cast grid.

The depth of the fluidized bed within the reactor is determined by the position of the clinker overflow pipe. This water-jacketed pipe extends through the carbon steel shell and refractory lining of the vessel and forms the outlet for the clinker particles moving around within the fluidized bed. The fluidization of relatively large-diameter particles with hot combustion gases usually produces a type of fluidization which is similar to a rapidly boiling and agitated liquid. Therefore, as the upper surface of the fluidized bed moves in the form of waves, and as bubbles burst through the surface, the undulating and probably splashing effect of these phenomena would cause the bed to wash up over the clinker overflow, thereby discharging clinker particles with each cycle of this kind of wave motion.

3. Mechanical Advantages

During the 1950's and 1960's, the cement industry installed progressively larger rotary kilns. This trend was motivated by the increased profitability of larger cement plants which derived from the economies of scale for large plants based on only one or two large rotary kilns rather than many smaller ones. In the late 1950's and early 1960's, kilns being installed ranged up to 27 ft in diameter and 700 ft long. These are probably the largest and heaviest rotating pieces of processing equipment used by any industry.

A rotary kiln consists of a cylindrical welded-steel plate shell lined with refractory brick and encircled along its length with steel rings, called tires. Each tire rests on a pair of steel support rollers or bearings. Because of the great weight of such an assemblage, some shell deformation is unavoidable. When viewed from the end, a large rotary kiln is oval shaped, as the weight of the kiln tends to flatten it slightly. This distortion produces a regular cycle of major stresses as the kiln rotates. These stresses are not a serious problem in the elastic steel kiln shell, but are a problem in the refractory brick. The rigidity of refractory brick, combined with its low tensile strength, is responsible for increasing brick damage (e.g., spalling) in the larger rotary kilns. This results in a significant shortening of the refractory life, and increased refractory cost in the larger rotary kilns.

By contrast, the fluidized-bed reactor is a vertical cylinder of rather low height and large diameter. The reactor does not rotate or move in any other way. Although it consists of a steel shell lined with refractory brick, none of the refractory problems of the rotary kiln apply to the fluidized-bed reactor. Therefore, refractory life in the fluidized-bed process is expected to be high.

In the rotary kiln, because of the high flame temperatures which result from the suspension combustion of fuel, it is necessary to protect the refractory brick in the clinkering zone with a coating of sticky or semi-plastic clinkering raw material, deliberately induced by its composition. Even more important is the protection of the refractory from the highly abrasive action of the clinker particles which roll along the inner surface of the rotary kiln. Without such a coating, refractory bricks are quickly worn too thin to protect the steel shell.

The down-time required for cooling the kiln, removing the worn brick, rebricking, and startup is in itself a significant interruption leading to loss of production. In addition the cost of refractories is quite high. The sum of these two items can amount to a significant manufacturing cost item.

Refractory life in the fluidized-bed cement reactor, however, is extremely high because the walls are vertical, the clinker particles are small and spherical, and the impact of fluidized particles on the vertical inner wall of the fluidized-bed reactor is cushioned by the suspension of the particles in air and the flow of air around the particles. The production and maintenance of a coating of clinkering raw material is not necessary on the inner surface of the brick lining the fluidized-bed cement reactor.

The fluidized-bed cement reactor is also a more compact piece of equipment than the rotary kiln. For example, a fluidized-bed reactor with a production capacity of about 250,000 tpy of cement clinker would have an outside diameter of approximately 23 ft and be 50 ft tall. By contrast, a dry-process rotary kiln of similar capacity would be 11 ft in diameter and 375 ft long (wet process - 12 ft diameter by 450 ft long).

A rotary kiln requires a complex and expensive drive mechanism and speed control, which the fluidized-bed cement reactor does not need. Air in-leakage with its attendant energy losses is common to rotary kilns, but is not a problem for the fluidized-bed cement process.

However, all of the combustion air supplied to the fluidized-bed reactor must be provided at a pressure high enough to overcome the resistance to flow, or pressure drop, it experiences as it passes through the air preheating system, through the air distribution grid which forms the floor of the reactor vessel, and finally through the fluidized bed of particles. A considerable expenditure of energy is required to drive the blowers for fluidizing air compression.

Another advantage of the fluidized-bed clinkering process is the ease with which clinker production can be changed from one type to another, primarily because of the absence of a coating (of either clinker or calcined raw material) on the inner surface of the refractory brick which lines the reactor. Also, the total inventory of clinker within the reactor is relatively small, and it can be displaced by the formation of new clinker in a relatively short time.

4. Energy Use

a. Comparison of Fluidized Bed with Rotary Kiln

Table IV-13 shows the comparative energy use of the conventional rotary kiln versus the fluidized bed. In the conventional rotary kiln, the hot combustion gases and the incoming cold raw materials pass continuously in a countercurrent manner. The raw materials are gradually heated to the final clinkering temperature, in excess of 2400°F. The combustion gases and the reactants, or raw materials, are at their highest temperature at the firing end of the kiln, where the fuel is burned in suspension within the kiln itself. The combustion gases pass through the kiln simultaneously giving up heat to the raw materials in the kiln and are at their lowest temperature at the gas discharge end, which is also the raw material feed inlet end, of the kiln.

The temperature of the combustion gases exiting from a long dry process rotary cement kiln which has a relatively high fuel consumption (e.g., 4.0-4.4 x 10^6 Btu/ton), is 1300-1400°F. A long dry-process rotary cement kiln of approximately the same capacity (1300-1400 tpd), with chains hung in the preheating section and exhibiting low fuel consumption (e.g., 3.4-3.6 x 10^6 Btu/ton) has an exit gas temperature of 800-900°F. The combustion gas has been cooled from near flame temperature to this relatively low temperature by countercurrent heat exchange with the incoming raw material feed stream. By contrast, the combustion gases which exit from the fluidized-bed cement reactor leave at the bed temperature, which is approximately 2400°F.

TABLE IV-13

COMPARISON OF TYPICAL ENERGY REQUIREMENTS
FOR FLUIDIZED-BED PROCESS AND LONG KILN
(Btu/ton Cement)

	Feed Preparation (quarry, crush, dry, mix feed)	Clinkering (burn, cool)	Finishing (grind, pack)	Available Energy Recovery (steam/power generation, dryer fuel savings)	Net Energy Required After Energy Recovery
S.D. Fluidized-Bed Kiln					
Electrical	490,000	-	760,000	(1,400,000)	(150,000)
Fuel	310,000	5,000,000	-	(180,000)	5,130,000
Total	800,000	5,000,000	760,000	(1,580,000)	4,980,000
Dry, Long Kiln					
Electrical	534,000	315,000	760,000	-	1,609,000
Fuel	336,000	4,600,000	-	(320,000)	4,616,000
Total	870,000	4,915,000	760,000	(320,000)	6,225,000

Source: Margiloff, I.B. and R.F. Cascone, Rock Products Cement Industry Seminar, Chicago, December 8, 1975.

In the conventional rotary kiln, the raw material feed is preheated by the exiting combustion gases to temperatures where the rate of thermal decomposition of the calcium carbonate constituent of the raw feed becomes relatively high. Carbon dioxide is then liberated from the calcining raw material. This calcination occurs over a temperature range of approximately 1200-1600°F. Therefore all of the carbon dioxide liberated from the raw feed in the calcination zone has only been heated to the calcination temperature.

In the fluidized-bed clinkering reactor, however, all of the carbon dioxide contained in the original calcium carbonate reactant is heated to 2400°F, since the entire reactor content of raw material and finished clinker is at a uniform clinkering temperature of 2400°F. Since about 35% of cement raw feed is liberated as carbon dioxide during the calcination process the fluidized-bed reactor subjects almost 50% more solid reacting materials to a temperature range from approximately 1400°F to 2400°F. The heat required to increase the temperature of all of the carbon dioxide from 1400°F to 2400°F represents an additional heat load in the fluidized-bed cement reactor which the conventional rotary kiln does not require.

Another difference in thermal or fuel energy use between the fluidized-bed reactor and the conventional rotary kiln relates to the recycle of the fine fraction of clinker particles. The clinker product which leaves the fluidized-bed represents the average particle size distribution within the bed of fluidized clinker particles. Therefore, there is a fine fraction of clinker particles leaving the fluidized-bed reactor which must be returned for further growth until it becomes larger than approximately 8 mesh.

The present process concept employs a cooler to reduce the temperature of the clinker from 2400°F to almost ambient temperature, for easy handling of the clinker, and to recuperate heat from the hot clinker particles. The cooled clinker is screened, the +8-mesh fraction being sent on to clinker product storage. The -8-mesh fraction is recycled to the reactor (with a part of it first being crushed, as described earlier).

Since the recycled clinker is essentially at ambient temperature, it must be preheated again to 2400°F. This is accomplished through the extraction of heat from the hot particles within the reactor. This extra step requires burning of additional fuel and is not part of the operation of a conventional cement rotary kiln.

b. Specific Requirements

Any form of carbonaceous fuel can be used in the fluidized-bed reactor. Semi-commercial scale demonstrations have been successfully accomplished using the following fuel forms:

- natural gas
- fuel oil (No. 4 and No. 6)

- bituminous coal
- petroleum coke
- oil shale (where the shale was one of the raw material constituents).

The fluidized-bed cement process compares favorably with the most energy-efficient current cement plant design.

(1) Raw Material Preparation[*]

The total energy used for the raw material preparation steps would be the same for conventional rotary kiln plants and the fluidized-bed cement process. Dry grinding operations all consume about the same amount of electrical power per ton of raw mix. However, wet grinding consumes less power, and since the fluidized-bed cement process is a dry one, this difference would indeed exist. Most of the new cement plants are dry process plants, indicating the beginning of a major trend in the United States away from the wet process cement plant. (See Appendices A,B, and C.)

In a rotary kiln, the typical loss of potential clinker through the wasting of kiln dust is about 8% of the raw material, whereas in the fluidized-bed reactor, only about 3% of the clinker equivalence of the raw material is lost. Therefore, less raw material is required to produce a ton of cement by the fluidized-bed process then by the conventional rotary kiln process. This higher yield of product per ton of raw material with the fluidized-bed process has, of course, an attendant savings in total energy required for raw material preparation.

(2) Clinker Production

The process design studies which have been conducted by Scientific Design Company indicate that the fluidized-bed clinkering reactor requires as much purchased fuel as the long dry rotary kiln equipped with a chain preheating section but less purchased fuel than the typical wet-process rotary kiln. Since the steam from the hot combustion gases leaving the fluidized-bed reactor generates power which is projected to be significantly in excess of that required to drive the fluidization air blowers, Table IV-13 shows the typical energy requirement in Btu/ton of cement, and neither credits nor debits this amount of power. However, the power in excess of this amount, from the steam generation system, which can be used in other areas of the cement plant, is shown on this table.

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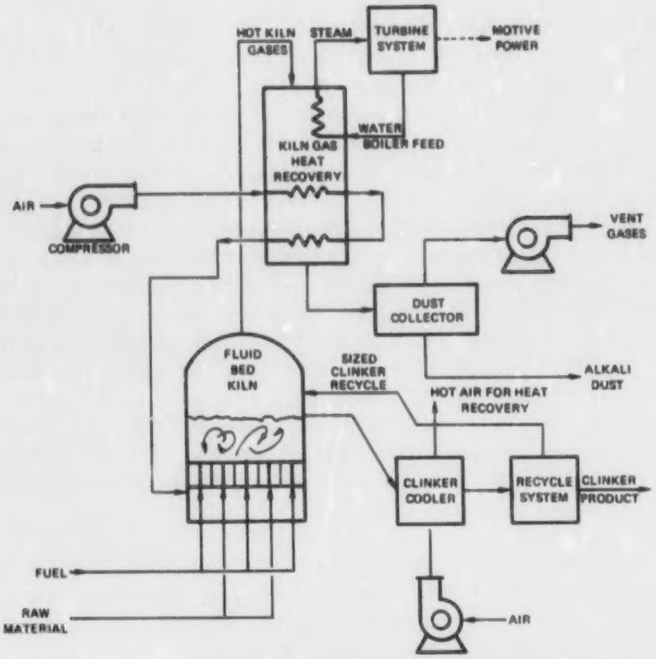
[*] Figure IV-9 is a schematic process flow diagram which shows the main components and important material flow streams for the fluidized-bed clinkering sections of a cement plant. The reactor is as described in the preceding section.


HOT KILN GASES
STEAM
TURBINE SYSTEM
MOTIVE POWER
WATER
BOILER FEED
KILN GAS HEAT RECOVERY
AIR
COMPRESSOR
VENT GASES
DUST COLLECTOR
FLUID BED KILN
SIZED CLINKER RECYCLE
ALKALI DUST
HOT AIR FOR HEAT RECOVERY
CLINKER COOLER
RECYCLE SYSTEM
CLINKER PRODUCT
FUEL
RAW MATERIAL
AIR

Source: Margiloff, I.B. and R.F. Cascone, Rock Products, Cement Industry Seminar, Dec. 8, 1975.

Figure IV-9. Scientific Design Fluid-Bed Cement Process

A pressurized feeder conveys a dense fluidized stream of cement-making raw materials at a suitably high pressure and at a controlled feed rate into the fluidized bed of hot portland cement clinker particles through one or more transfer lines. The overflow of hot cement clinker from the fluidized-bed reactor discharges from the overflow pipe by gravity into a clinker cooler. A horizontal reciprocating grate cooler of the type designed and built by Fuller Company probably would suitably handle and cool such a spherical product. The cooled clinker is screened to separate the clinker product from the recycled material.

Fuel is introduced through fuel transport lines in a manner analogous to the raw material feed. A gaseous or liquid fuel would be pumped directly into the bed, probably through the cast refractory grid. A crushed solid fuel, such as coal or petroleum coke, would probably be introduced through the grid. The raw material and the fuels would be introduced at the bottom of the fluidized bed to maximize their residence time. The hot combustion gases leaving the reactor at 2400°F would pass through a heat exchanger, which would transfer heat from these hot gases to incoming cold fluidizing and combustion air, as well as to water for the generation of steam. Probably the heat exchanger would be divided into two sections, which would exist in series. The first section would receive the hottest gas leaving the reactor and would be designed to exchange radiant heat energy from the hot gas to the fluidizing and combustion air contained in alloy tubes, for the generation of steam, or for both of these options operating together. After the combustion gases leaving the reactor have been cooled to a temperature sufficiently low so that the radiant component of the gases' heat transfer capability are sufficiently diminished, the cooler gases would probably pass through a conventional preheating unit. This unit would do the initial heating of the fluidizing and combustion air and/or heating of water condensed from a steam system. The steam generated in such a heat exchanger would be used either to directly drive the air blowers required to supply the pressurized fluidizing and combustion air to the reactor or to generate electrical energy through a turbine drive which could in turn power an electric motor drive connected to the air blower system. The steam generated by such a system would be in excess of that required simply for providing the pressurized fluidizing and combustion air for the fluidized-bed reactor. In fact, sufficient steam is available (after all of the heat that can be utilized in preheating the fluidizing and combustion air has been extracted from the combustion gases leaving the reactor) to provide electrical energy not only for grinding all of the raw material required by the fluid-bed reactor but also to drive the finish cement grinding mill.

Therefore, in addition to fuel, the only other uilities which are apparently required for the fluidized-bed cement process are cooling water (or air coolers) for condensation of turbine exhaust steam and a small amount of boiler feedwater makeup for the steam system.

This makes the fluidized-bed cement process competitive on a total energy basis with the most energy efficient cement-making processes presently available to the portlant cement industry, namely the suspension-preheater-equipped rotary kiln, and the flash-calciner-equipped suspension preheater rotary kiln facility. In addition to the recuperation of heat from the hot combustion gases leaving the fluidized-bed reactor, the hot air leaving the clinker cooler provides another source of high-temperature gases which can be utilized to reduce the overall energy required by this process. Either the highest temperature cooling air exiting from the hot clinker inlet end of the cooler can be sent to the convection section of the main heat exchanger for the initial preheating of the fluidizing and combustion air and/or the initial heating of the feedwater to the steam generator, or else that hot air can be utilized for the preheating of the cement raw feed.

An additional advantage of the fluid-bed process is that the raw feed particles would be kept isolated from the hot combustion gases leaving the fluidized-bed reactor, and therefore would not become contaminated by the volatilized alkali elements leaving the clinkering raw feed in the fluidized bed. This alkali volatilization characteristic of the fluidized-bed clinkering process is a significant advantage and results in large part from the totally indirect heat transfer between the hot combustion gases carrying the alkali values from the bed of clinkering materials and any of the air or raw material inlet streams to that reactor.

(3) Power Recovery

The fourth column in Table IV-13 is the excess heat from clinkering which is recoverable as steam suitable for power generation. This includes steam generated in excess of that required for driving the blowers for the pressurized fluidizing air, exit gas fan, cooler air fan, etc., all of which are associated with the fluidized-bed clinkering reactor system. This also includes heat recoverable from the hot air leaving the clinker cooler. The fuel credits shown in this column assume that available heat (down to 300°F) in the flue gases or heated air is limited only to the heat that can be used for feed drying in that particular train of the production system, although more heat may actually be available in those particular streams.

The electrical energy required is based on a 30% fuel efficiency on delivered power, and a 26% efficiency of captively generated power to convert electrical power requirements to the equivalent and actually required fuel energy for that electrical power generation. The fifth column of Table IV-13, shows the net energy required, including energy recovery. In the case of the fluid-bed cement process, all of the steam which can be generated in excess of that required to supply the motive power for the fluidized-bed clinkering system has been considered available for use in the other areas of the cement plant, such as for driving the ball mills for raw material grinding and finished cement grinding.

On a total energy basis, the process design studies recently conducted by Scientific Design Company indicate that the cement process employing the fluidized-bed cement reactor, with proper heat recovery, requires significantly less total energy than either the conventional wet or dry long rotary kiln, and actually is close to the preheater-equipped short rotary kiln, which represents the most energy-efficient cement clinkering process available to the cement industry today.

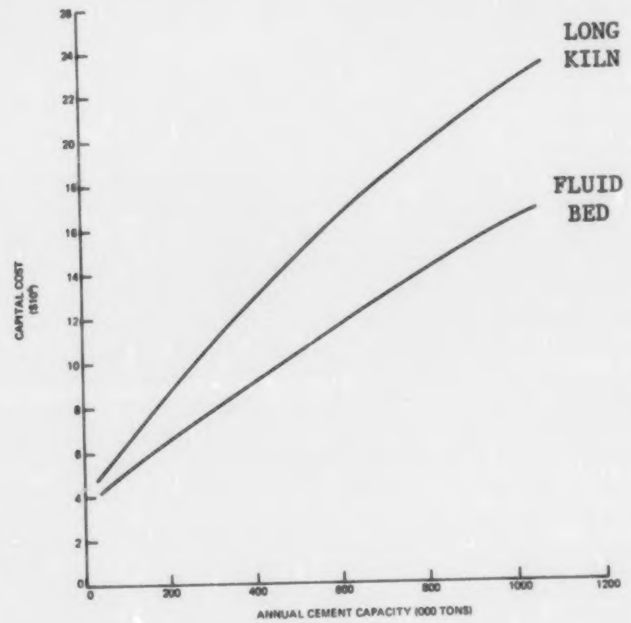
Further savings in purchased fuel can be achieved through the use of raw materials containing fuel values such as the kerogen contained in oil shale. Also, when rotary kiln waste dust is used as the raw feed or forms a portion of the raw feed to the fluidized-bed clinkering reactor, significant savings in purchased fuel can be achieved since kiln dust has already been subjected to some degree of calcination. For example, cement clinker can be produced in a fluidized-bed reactor using 100% kiln dust (with a suitable correction of the calcium, silicon, iron, and aluminum values to make the proper balance of portland cement compounds) with a savings of up to 2 x 10^6 Btu/ton of clinker produced. This would reduce the total energy required to approximately 3 x 10^6 Btu/ton of cement, including the fuel energy required to produce all of the electrical power for operating the entire cement plant built around the fluidized-bed clinkering reactor.

5. Economic Factors

a. Fixed Capital Investment

Figure IV-10 shows the total fixed capital cost associated with the clinkering section only for the Scientific Design fluid-bed kiln and the long kiln with chain section. This figure shows the fixed capital investment, in 1975 dollars, as a function of the annual installed cement production capacity. Fixed capital investment includes the purchase cost of all major items of equipment, and other materials such as instrumentation, insulation, foundations, etc. Also included are the construction labor and construction supervision required to build the facility, and all design, engineering, procurement, and expediting costs.

These fixed capital investment figures are only for the clinkering sector, and do not include the front end of the cement plant which begins in the quarry, and proceeds through the raw material grinding and blending system, or the back end of the cement plant which begins with portland cement clinker and proceeds through crushing, finish grinding, and storage. However, since the front and back end of the cement plant will be essentially the same for both processes shown, and the only difference in design and fixed capital costs is in the clinkering section, this figure clearly compares the standard or present state-of-the-art clinkering process used by the cement industry with the fluidized-bed clinkering system.



*NO COST ESCALATION CONTINGENCIES INCLUDED

Source: Margilot I.B., and R.F. Cascone, Rock Products, Cement Industry Seminar, Chicago, Dec. 8, 1975.

Figure IV-10. Total Capital Costs of Various Clinkering Sections, April, 1975

TABLE IV-14

PORTLAND CEMENT PRODUCTION COST: FLUIDIZED-BED CEMENT PROCESS

Product: Type I Portland Cement
Byproducts: None
Annual Capacity: 445,500 tons
Annual Production: 445,500 tons

Process: Fluidized-Bed Clinker Reactor
Fixed Investment: $38 x 10^6

Working Captial: $2.8 x 10^6
Stream Days/Yr.: 330
Location: U.S. East Coast

	Units	Quantity/Ton	Unit Cost	$/Ton
VARIABLE COSTS				
Raw Materials: Limestone		included in other costs		
Argillaceous Components		included in other costs		
Gypsum				1.00
Purchased Energy: Fuel (Oil)	10^6 Btu	5.0	2.0	10.00
Water: Cooling	10^3 gal	3.45	0.03	0.10
Operating Labor	Man-hour	0.06	6.00	3.60
Labor Overhead		30% of Operating Labor		1.08
Operating, Main. & Repair Supplies		2% of Plant Cost		1.71
FIXED COSTS				
Plant Overhead		70% of Operating Labor		2.52
Taxes & Insurance		2% of Plant Cost		1.71
Depreciation		20 year, straight line		4.26
TOTAL PRODUCTION COST				25.98
Pre-Tax Return on Investment		20%		18.32
TOTAL				44.30

Source: Arthur D. Little, Inc. estimate.

It is interesting to note the significantly lower fixed capital investment required for the fluidized-bed process as envisioned by Scientific Design Company compared to that of the long kiln. Scientific Design Company indicated that the fixed capital investments for the various modern rotary kiln systems were independently estimated by cement specialists. If waste kiln dust is used as the primary or as a major raw material component, the feed grinding department capital investment will be reduced.

b. Operating Cost

Table IV-14 shows our estimate of cement manufacturing cost for a fluid-bed cement process plant of 1350 tpd, or 445,500 tpy capacity. The objective of this estimate is to compare the fluidized-bed process costs with the conventional long rotary kiln cement process plant manufacturing costs in order to identify the significant differences.

6. Environmental Factors

a. Air Pollution

The main effluent stream from the fluidized-bed cement process is the combustion gas stream leaving the reactor. This stream is analogous to the hot combustion gas stream leaving the conventional rotary cement kiln. With regard to its main gaseous and vapor constituents, such as nitrogen, carbon dioxide, etc., the two principal differences between the effluent gas streams from the conventional rotary kiln and the fluidized-bed cement reactor are the quantity and composition of the solid particulates carried by that gas stream and the concentration of NO_x.

Table IV-15 shows our estimated operating costs for the air pollution control system required by the fluid-bed cement process.

(1) Particulates

The composition of the solid particulates carried from the fluidized-bed cement reactor is very different from that of rotary kiln dust. Rotary kiln dust consists of partially calcined cement raw feed and potassium and sodium sulfates in the range of 5-10% total alkalies, expressed as the stoichiometric equivalent of sodium oxide. In contrast, it is reported that the solid particulates carried by the hot combustion gases exiting the fluidized-bed cement reactor consist of 97% water-soluble potassium and sodium sulfates, and 3% cement clinker. Therefore, since the dust from the fluidized-bed process is essentially pure potassium and sodium sulfate, the quantity of dust collected per ton of cement clinker produced is very small compared with the dust collected from the conventional rotary kiln process.

The volume of dust which must be disposed of per ton of cement produced by the fluidized-bed cement process is consequently only a small fraction of the volume which must be discarded from the conventional rotary kiln process. In addition, since the dust from the fluidized-bed cement process is essentially pure potassium and sodium sulfate, it is readily water-soluble, and contains almost no hydraulically cementitious materials, it should be technically

TABLE IV-15

OPERATING COSTS FOR AIR POLLUTION CONTROL SYSTEM: FLUIDIZED-BED CEMENT PROCESS

Production, ton/yr	470,000
Fuel Required, Btu/ton	5.0×10^6
Capital Investment, $	939,000
Control Device (Fluidized Bed, Cooler)	Glass Bag Filter
Annual Operating Costs:	
Electricity (2.17×10^6 kWh/yr), $/yr	43,300
Direct Labor (11,340 hr/yr), $/yr	68,040
Maintenance Labor (5,700 hr/yr), $/yr	39,900
Plant Overhead, $/yr	107,940
Materials, $/yr	79,800
Depreciation, $/yr	46,950
Taxes and Insurance, $/yr	18,800
Return on Investment, $/yr	187,800
Total Operating Cost, $/yr	592,530
Total Operating Cost, $/ton	1.26
Energy Consumption, 10^9 Btu/yr	22.79
Energy Consumption, Btu/ton	48,500

Source: Arthur D. Little, Inc. estimate

feasible, and perhaps even economically attractive to further process this dust to extract potassium sulfate, which could have commercial value, for instance as a plant nutrient.

(2) Alkali Volatilization (Particulates Source)

An important advantage of the fluidized-bed cement reactor over the conventional rotary kiln is the very high degree of alkali volatilization from the raw materials during their conversion to cement clinker. The direct contact between the hot combustion gases and the raw feed in the rotary kiln is responsible for the recirculation of volatilized alkalies between the high-temperature clinkering zone (where the alkali values are liberated from the raw materials and become a vapor species) and the cool end of the rotary kiln where the combustion gases leave the kiln after giving up much of their heat by direct contact with the incoming cold raw material.

By contrast, the hot combustion gases leaving the fluidized-bed reactor give up their heat indirectly, through steel heat transfer surfaces to the incoming fluidization and combustion air, to water and steam in the steam generating portion of the heat exchange system. Therefore, as the potassium and sodium sulfate vapor condenses into a fume in the hot combustion gases passing through the heat exchange system, these alkali particulates are kept from contact with the incoming cement raw feed. Since there is no route by which the volatilized alkali compounds can be returned to the bed of clinker in the fluidized-bed reactor system the alkalies, once volatilized, will leave the clinkering system and be removed from the cooled combustion gases by appropriate dust removal equipment, such as glass cloth filters.

In addition to the indirect heat transfer between the hot combustion gases carrying the alkali sulfates and any of the incoming material streams to the reactor, other factors which are probably responsible for the high degree of alkali volatilization demonstrated by the fluidized-bed cement reactor are as follows:

- Fluidized beds characteristically demonstrate extremely high heat transfer and mass transfer rates. Therefore, the temperature and combustion gas composition is expected to be quite constant throughout the continuous fluidizing gas medium phase in the fluidized bed, which should tend to maximize the volatilization efficiency.

- The long residence time of the cement clinker particles in the high temperature (2400°F) in the fluidized-bed reactor compared with the relatively short period of time that the reactants are in the high-temperature clinkering zone of a rotary kiln. The extent of volatilization should increase in proportion to residence time.

- The raw feed particles (containing the highest quantity of alkali materials present in the fluidized-bed system) are deposited on the surface of the individual fluidized-bed particles. Since the total surface area of these small particles is large, and the thickness of the new incremental layer of clinker deposited on each particle at any time is probably very small, the distance for diffusion of the alkali components is short. Clinker particles in a rotary kiln are quite large in diameter, compared with the average diameter of the clinker spheres in the fluidized-bed cement process.

(3) Nitrogen Oxides

Combustion conditions in the rotary cement kiln favor NO_x formation, due to the high peak flame temperatures associated with the combustion of fuel in suspension, as well as the existence of regions of high oxygen concentration due to the absence of good fuel/air mixing, further enhanced by in-leakage of ambient air through the rotary kiln seal.

By contrast, the fluidized-bed cement reactor operates at a constant and uniform temperature of 2400°F, which is considerably below the peak flame temperatures in a rotary kiln. This temperature is constant and uniformly distributed throughout the entire volume of the fluidized bed, due to the excellent heat and mass transfer characteristics of fluidized beds. Finally, because of the excellent mass transfer exhibited by fluidized beds, the oxygen concentration in the gas phase within the bed is quite uniform at any elevation, thereby preventing regions of high oxygen concentration.

Figure IV-11 compares the emission of nitrogen oxides, expressed as NO_x, from a fluidized-bed reactor and from a rotary kiln, both being operated to produce solid products at 2400°F. The fuel used during these tests was oil, and percent stoichiometric air was the independent variable. The fluidized bed clearly generates significantly less NO_x than the rotary kiln.

b. Water Pollution

The wastewater generated by a cement plant employing the fluidized-bed process will be similar in composition but different in flow rate from that of the base cement plant. (See Appendix C.)

The incorporation of steam generation facilities within the fluidized-bed process configuration greatly increases the amount of non-contact cooling water generated. The amount of cooling water generated is estimated as follows:

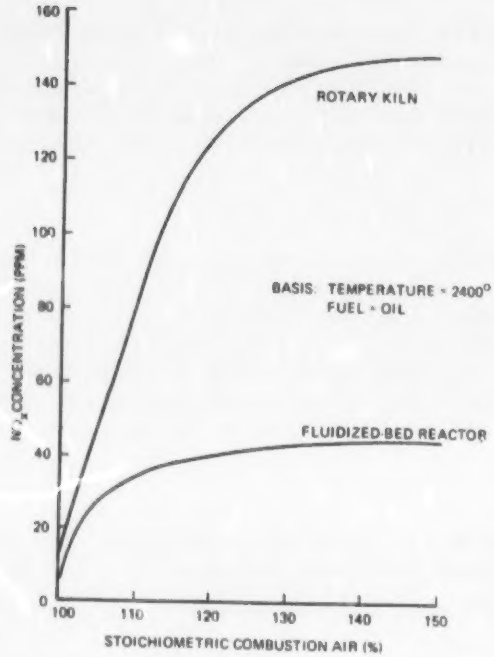
	gpd
Plant Cooling Water (same as base case)	648,000
Steam Generation Condenser Waste	4,320,000
Total Non-Contact Cooling Water	4,968,000

Due to restrictions on wastewater temperature rise imposed upon the cement industry (maximum permissible temperature rise above inlet water = 3°C), it will be necessary to cool the exit cooling water prior to discharge. As in the base case cement plant, it is anticipated that a spray pond would be the most practical means of cooling. Since the total non-contact cooling water flow rate is much greater than that of the base case (4,968,000 gpd vs 648,000 gpd), the spray pond will be larger and more costly.

The steam generation facilities will also produce wastewater streams consisting of boiler blowdown and boiler feedwater treatment regeneration brines, both of which are small in volume and largely contain inorganic salts; they are not considered in the cost comparison.

Cement plants employing the fluidized-bed process will produce a waste dust, which for a 1350-tpd cement plant is estimated to be generated at a rate of 40 tpd. Unlike the base case cement plant, dust generated by the fluidized-bed process will consist of relatively high-grade potassium and sodium sulfate, both of which are highly soluble. There are possibilities for selling this material as a byproduct. However, if the material cannot be sold as a byproduct, it will have to be stored on-site in a manner similar to that described for the base case. The high solubility of the material imposes even a stronger need to dike the storage area and to collect and treat runoff water.

The run-off would be treated primarily to remove suspended solids and soluble heavy metals. Dissolved species, such as potassium, sodium and sulfate, would be much more difficult to remove, and probably would not need to be removed.



Source: Lewall, T.R. and Cohen, S.M., Paper presented at A.I.Ch.E., Cincinnati meeting, May 1971.

Figure IV-11. Comparison of NO_x Emissions from Fluidized-Bed Reactor and Rotary Kiln

Due to the smaller quantity of dust generated, the required storage area will be smaller than that of the base case (3.0 acres for a 10-year storage area 20 feet deep vs 10.6 acres for the base case cement plant).

Due to the greatly increased cooling water flow rate, the unit treatment cost is substantially greater than that of the base case - \$0.84/ton vs \$0.45/ton for the base case. (See Table IV-16.)

c. Solid Wastes

The main solid waste is the collected particulate material. When firing a rotary kiln with coal, some of the coal ash is carried out of the kiln with the combustion gases, and forms part of the collected kiln dust. Any of the heavy metals commonly present in this ash can be leached out of such kiln dust storage piles by rainwater.

Essentially all of the coal ash generated within a coal-fired, fluid-bed cement reactor will form part of the clinker. Therefore, the dust from the coal-fired fluid bed should have a much lower coal ash content.

TABLE IV-16

WASTEWATER TREATMENT COSTS: FLUIDIZED BED

Basis 1350 tpd Cement Product
330 Operating Days Per Year

CAPITAL INVESTMENT - $937,000

	Annual Quantity	Cost Per Unit Quantity	Quantity Per Ton of Production	Unit Cost ($ Per Ton of Product)
VARIABLE COSTS				
Operating Labor (including overhead)	3125 man-hr	$12/hr	0.007	0.0842
Maintenance (inc. lbr & mtls)				0.0842
Chemicals Sulfuric acid	4 tons	$100/ton	9.0×10^{-6}	0.0009
Electrical Power	2,283,200/ kWh	$0.02/kWh	5.13	0.1025
TOTAL VARIABLE COST				0.2718
FIXED COST				
(Depreciation @ 5%)				0.1053
(Taxes & Insurance @ 2%)				0.0420
TOTAL FIXED COST				0.1473
TOTAL ANNUAL COST				0.4191
RETURN ON INVESTMENT @ 20%				0.4207
TOTAL				0.84/ton

Notes:

1) Capital investment adjusted to 1975 level (ENR Construction Cost Index = 2126)

2) Wastewater treatment includes:
   a) Non-contact cooling water (plant cooling water plus steam generation condenser cooling water) thermal pollution control via spray pond
   b) Dust pile runoff containment, collection, clarification and neutralization

3) Estimates are for the specific example of a dry-process, non-leaching cement plant and are in no way intended to represent industry-wide wastewater treatment costs.

Source: Arthur D. Little, Inc. estimates

D. CONVERSION TO COAL FUEL FROM OIL AND NATURAL GAS

1. Background

Portland cement is manufactured in most of the countries of the world using all commercially available carbonaceous fuels and, in some cases, unusual fuels which are not commercially used by other industries. The majority of cement plants use a rotary kiln for the clinkering reactor. Most of the fuel used in the cement-making process is burned in the rotary kiln, where it is burned in suspension and forms a free-standing flame in one end of the kiln.

The specific fuels which are used, or have been used, for manufacturing portland cement in a rotary kiln are:

- natural gas
- crude oil
- fuel oil (primarily No. 6)
- anthracite coal
- bituminous coal
- petroleum coke
- various waste materials such as peanut shells
- combinations of the above, such as:
  - anthracite coal/bituminous coal
  - anthracite coal/No. 6 fuel oil

The specific fuel or combination of fuels used to produce portland cement clinker in a rotary kiln has an effect upon:

- burner design
- ratio of combustion air to fuel
- ratio of primary to secondary combustion air.

With a rather wide latitude in the interchangeability of fuels burned in any specific rotary kiln installation, essentially any rotary kiln now being fired by gas or oil can be converted to coal.

2. Coal-Firing Factors

The air necessary to sustain combustion of the fuel comprises primary air, which enters the kiln along with the fuel, and secondary air, normally hot air obtained from the clinker cooler. When firing with pulverized coal, primary air may be as much as 25% of the total quantity of combustion air supplied, depending upon the kind of coal employed and the draft provided within the kiln by the induced draft fan. When firing with oil or gas, primary air is only about 3% of the total combustion air, since these fuels do not require air as a carrier medium for the fuel. An advantage of firing pulverized coal is that the primary air can be preheated to significantly higher temperatures than with oil or gas. The fineness to which coal must be pulverized or ground to burn properly in a rotary kiln depends to a large degree upon its ash content and also its rank (percent volatile matter). As the coal ash content increases, or as the volatile matter decreases, the fineness to which the coal must be ground increases (Table IV-17).

3. Conversion to Coal Firing

In converting a rotary kiln now burning gas or oil to coal, the following areas of manufacturing process technology, plant operation, and plant equipment must be considered.

TABLE IV-17

REQUIRED PULVERIZED-FUEL FINENESS AT MAXIMUM RATING

(Percent through 200 U.S.S. Sieve*)

ASTM CLASSIFICATION OF COALS BY RANK

	Fixed Carbon (%)			Fixed Carbon below 69%		
Type of Furnace	97.9-86 Petroleum coke	85.9-78	77.9-69	Btu above 13,000	Btu 12,900-11,000	Btu below 11,000
Marine boiler furnace	-	85	80	80	75	-
Water-cooled furnace	80	75	70	70	65**	60**
Cement kiln	90	85	80	80	80	-
Metallurgical		(As determined by process, generally from 80 to 90%)				

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*The 200-mesh screen (sieve) has 200 openings per linear inch, or 40,000 openings per square inch. From U.S. and ASTM sieve series, the nominal aperture for 200 mesh is 0.0029 inch, or 0.074 mm. The ASTM designation for 200 mesh is 74 microns.

**Extremely high-ash-content coals will require higher fineness than indicated.

Source: Schwarzkopf, F., Rock Products, July 1974

a. Raw Feed Chemistry

Coal is a unique fuel for the manufacture of portland cement, since it contributes a substantial amount of ash to the interior of the rotary kiln. Chemically, coal ash consists primarily of silicon, iron, aluminum, sodium, and a host of other elements in decreasing percentages. Because of their form in the original minerals, and also because of the high temperature of the oxidizing atmosphere within the combustion zone, coal ash consists primarily of glassy or amorphous silica, iron oxide, aluminum oxide, sodium sulfate, and other elemental oxides, many of which have combined into various complex solid combinations.

Typical bituminous coal contains approximately 10% ash by weight. Between 50% and 100% of all of the coal ash produced by the combustion of coal in a rotary cement kiln contacts and chemically combines with the clinkering raw materials, thereby losing its identity as coal ash and becoming portland cement clinker. Since the coal ash has a chemical composition which is not at all appropriate for the production of portland cement clinker, the raw feed chemical composition must be adjusted to incorporate the quantity and composition of coal ash from the coal combustion in the rotary kiln. In this way - regularly done in the portland cement industry - the combination of raw feed and coal ash meets the specific and stringent chemical composition requirements for portland cement clinker. There is no adverse affect on the quality of the cement clinker if the raw feed has been adjusted to incorporate the coal ash, and if variations in the quantity and chemical composition of the coal ash accompanying the coal being burned can be predicted and suitable corrections made in the raw feed to the kiln.

b. Sulfur

The major potential problem associated with the use of coal as a fuel in manufacturing cement is the sulfur content of the coal. Portland cement typically contains between 1.5% and 2.5% sulfur, expressed as SO_3. Most of this sulfur comes from the deliberate addition of gypsum to portland cement clinker. This is done before final grinding to the finished, fine-powdered product, in order to increase the setting time of the concrete and allow sufficient time for mixing and placement. Without the addition of gypsum, most portland cement clinkers will produce a concrete with an unpredictable and extremely short setting time.

In addition to the sulfur contributed by the gypsum, the portland cement clinker itself contributes an amount of sulfur, usually in the form of potassium and sodium sulfate. This is rather uniformly distributed throughout each individual particle of ground clinker and has only a minor effect on setting time. The sulfur in the clinker originates from both the raw material components and the fuel used for clinkering. With the raw materials and fuels typically used by the industry, there is at least sufficient sulfur present in the kiln to stoichiometrically react with the alkali elements in the raw materials to produce potassium and sodium sulfate. Any additional sulfur usually exists in a dynamic equilibrium between sulfur oxides in the high-temperature burning end of the kiln, and calcium sulfate in the cooler, raw material feed end.

There are two main aspects to the effect of sulfur in the clinkering process. The first is the effect of sulfur upon the quality of the cement clinker, and upon the finished portland cement made from that clinker. The second is the effect upon the operation of the rotary kiln. The rotary kiln with a suspension preheater or a flash calciner is most affected by high levels of sulfur.

Operating experience has shown that a suspension-preheater-equipped rotary kiln (or the suspension preheater part of a flash calciner) experiences progressively more serious problems with sticking materials, clogging of transfer lines, and bridging of the bottom solids outlet portion of cyclone suspension vessels as the sulfur level in the rotary kiln/suspension preheater system increases. In particular, as the stoichiometric ratio between sulfur and the alkalies (potassium and sodium) increases above one, these problems become more pronounced. It appears that as long as the alkalies and sulfur are in balance, most of the sulfur forms potassium and sodium sulfate. However, as the sulfur is allowed to increase beyond this point, other low melting point phases, such as calcium sulfate, or combinations of alkali and calcium sulfate, or even other sulfates, form and concentrate between the rotary kiln and Stage 4 of the suspension preheater.

Although this additional sulfur does not significantly increase the level of SO_2 in the suspension preheater or flash calciner exit gases, the operational problems experienced within the suspension preheater or flash calciner can become so severe as to preclude the use of coal containing excessively high levels of sulfur. Unfortunately, it is not possible to generalize and cite some level of sulfur in coal which forms the threshold for severe operational problems, since the composition of the raw material, the content of alkalies in the raw material, and the specific clinkering and preheating system, all contribute importantly to the quality of clinkering process equipment performance or operation.

Excessive sulfur in portland cement can delay some of the hydration reactions too long beyond the final setting of the concrete. This results in considerable expansion within the concrete mass and consequent cracking of the finished structure. Because of this, all major cement-producing countries of the world have set maximum sulfur specifications on cement (Table IV-18).

It is, therefore, one of the operating goals of most of the world's cement plants to produce a clinker with as low a sulfur content as possible. This permits the greatest latitude in adding gypsum to control setting time. If the clinker sulfur content is too high, then it may not be possible to add the amount of gypsum actually required for set control and still have a cement which meets the specified maximum sulfur content. This would result in a product with poor or even unacceptable physical properties.

TABLE IV-18

MAXIMUM SULFUR SPECIFICATIONS FOR CEMENT IN SELECTED COUNTRIES

Country	Type of Cement	Maximum Sulfur Content (Wt % SO_3)
UNITED STATES	$3CaO \cdot Al_2O_3$ ≤8%	
	ASTM TYPE I	2.5
	ASTM TYPE II	2.5
	ASTM TYPE III	3.0
	ASTM TYPE IV	2.3
	ASTM TYPE V	2.3
	$3CaO \cdot Al_2O_3$ >8%	
	ASTM TYPE I	3.0
	ASTM TYPE III	4.0
JAPAN	Ordinary Portland Cement	2.5
	Rapid Hardening Portland Cement	2.8
	Medium Low Heat Portland Cement	2.5
	Portland Blast Furnace Cement (3 types)	3.0
	Pozzolanic Cement (3 types)	2.5
WEST GERMANY	Portlandzement (6 types)*	3.5
	Portlandzement (6 types)**	4.5
	Eisenportlandzement (4 types)*	3.5
	Eisenportlandzement (4 types)**	4.5
	Hochofenzement (5 types)*	4.0
	Hochofenzement (5 types)**	4.5
	Hochofenzement (5 types) [Containing more than 70% slag]	4.5
	Trasszement (3 types)*	3.5
	Trasszement (3 types)**	4.5
ITALY	Cemento Portland Normale	3.0
	Cemento Portland Ad Alta Resistenza	3.0
	Cemento d'Alto Forno	3.0
	Cemento d'Alto Forno Ad Alta Resistenza	3.0
	Cemento Pozzolanico	2.5
	Cemento Pozzolanico Ad Alta Resistenza	2.5
FRANCE	Ciment Portland (19 types)	3.5
	Ciment Portland de Fer (2 types)	3.5
	Ciment Métallurgique Mixte (2 types)	3.5
	Ciment de Haut Forneau (2 types)	3.5
	Ciment de Laitier au Clinker (2 types)	5.0
UNITED KINGDOM	Ordinary Portland Cement+	2.5
	Ordinary Portland Cement++	3.0
	Rapid Hardening Portland Cement+	2.5
	Rapid Hardening Portland Cement++	3.0
	Low Heat Portland Cement+	2.5
	Low Heat Portland Cement++	3.0
	Sulfate-Resisting Portland Cement	2.5
	Portland Blast Furnace Cement	6.75+++
SPAIN	Cemento Portland (3 types)	4.0
	Cemento Portland Resistente a Las Aguas Selenitosas (6 types)	4.0
	Cemento Portland Siderúrgico (2 types)	4.0
	Cemento Portland de Horno Alto (2 types)	4.0
	Cemento Puzolánico	4.0

Footnotes:

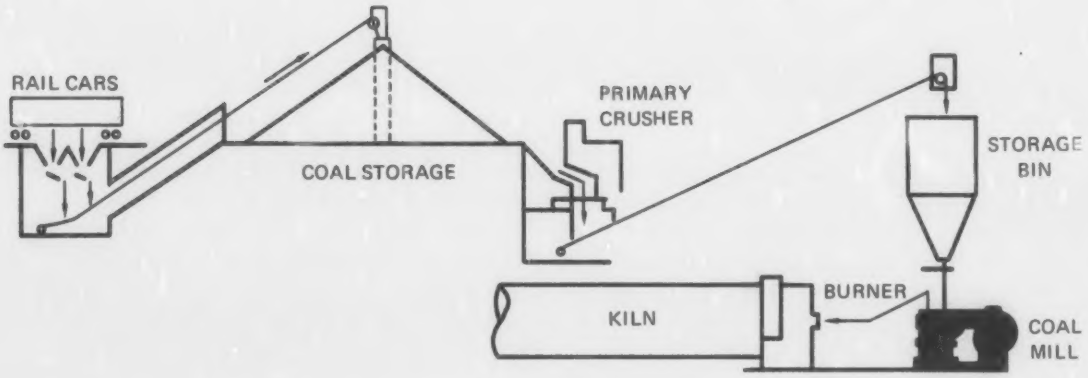
*Specific Surface ≤4,000 cm^2/g
**Specific Surface >4,000 cm^2/g
+$3CaO \cdot Al_2O_3$ ≤7%
++$3CaO \cdot Al_2O_3$ >7%
+++Max SO_3 = 3.0%
Max S = 1.5%

Source: "Cement Standards of the World", published by Cembureau, Paris, 1968.

c. Equipment

To convert a cement plant from gas or oil to coal firing, it is necessary to design and install the basic system for handling, processing, and burning that coal. The main elements of such a system for coal conversion are (Figure IV-12):

- coal unloading facilities
- storage
- secondary reclaiming
- primary crushing
- storage bunkers
- coal miliing
- feed to the kilns plus related conveyor systems
- appropriate instrumentation and controls.


RAIL CARS
COAL STORAGE
PRIMARY CRUSHER
STORAGE BIN
BURNER
KILN
COAL MILL

Source: Pit and Quarry, June, 1975.

Figure IV-12. Basic Elements in the Systems Installed to Convert to Coal Firing

4. Physical Facilities Required

a. Receiving

The typical portland cement plant uses fuel at such a high rate that (if it is burning coal) it justifies the receipt of coal by unit train. This will require the installation of enough track to receive and store all the cars of a unit train its unloading. A typical unit train might consist of 30-35 cars, carrying a minimum of 2000 tons of coal. Sufficient track for storing these cars, plus car handling equipment must be installed. Usually, demurrage charges begin 24 hours after arrival of a unit train. Therefore, the car handling and unloading system should be designed to permit unloading and rail car turnaround during that period.

b. Storage

Coal storage will be either open or covered. Covered storage is desirable, since it avoids coal pile run-off containment and treatment. However, the larger the cement plant, and consequently the quantity of coal to be stored, the more fixed capital investment is necessary for covered storage. At some cement plant size, open storage probably becomes economically justified. Open storage piles must be properly compacted to prevent fires and contamination and to minimize the buildup of moisture. Cement plants located in geographic areas of sufficiently severe winter weather must consider the use of de-icing compounds, such as calcium chloride, to permit recovery of coal as needed. The use of calcium chloride or other de-icing compounds adds to the coal pile run-off treatment necessary.

c. Reclaiming

Reclaiming is done either manually or automatically. Manual reclaiming requires the use of a piece of mobile equipment, such as a bulldozer, to move the coal from a stockpile into a reclaiming hopper from which the coal is then automatically fed to a conveyor for transfer to the rest of the system. Automatic reclaiming is done by locating feeders and a conveying system under the coal storage pile. A large outdoor coal storage area may require a bulldozer for maintaining the proper shape and compaction of the coal pile, whether automatic or manual reclaiming is used.

d. Pulverizing

Coal is usually pulverized in a ball mill or a roller mill. The roller mill is also referred to as a bowl, ring-roller, or ball-race mill. Typically, both types of mill are used in a direct-dash firing system, where the flow rate of coal to the mill is controlled or metered and the pulverized coal, as soon as it is sufficiently pulverized, is blown directly into the burner in the rotary kiln. In this system, there is no storage of fine pulverized coal. The indirect firing system uses an intermediate storage of fine pulverized coal, but the fire and explosion potential that accompanies such storage has discouraged its use.

5. Economic Aspects

a. Fixed Capital

The costs required to convert a cement plant from oil or gas to coal firing are highly site-specific. Therefore, the following example of a recent fuel conversion program is cited to provide a set of specific cost data.

Amcord, Inc., ranked seventh in cement production in the U.S., with an annual cement production capacity in excess of 4×10^6 tons, recently converted its western cement plants to coal from gas and oil. Three separate plants were converted, at a cost of $9 million. A total of 11 kilns are operated at three separate cement plant location (Table IV-19).

The Clarksdale, Arizona plant of Phoenix Cement was converted first. Actual construction on this 3-kiln plant began early in 1974. The 6-kiln conversion at Riverside Cement's Oro Grande, California plant followed. The third and final conversion, involving two kilns, was at the Crestmore plant at Riverside, California.

The annual production capacity of these three plants is 2.5×10^6 tons per year. The fixed capital investment required for this conversion to coal fuel, therefore, was $3.60 per annual ton of cement production capacity.

TABLE IV-19

PLANT CHARACTERIZATION DATA FOR THREE AMCORD PLANTS CONVERTED TO COAL FUEL

<table>
<tr><th>Plant Location</th><th colspan="2">Clarksdale, Arizona</th><th>Riverside, California</th><th colspan="3">Oro Grande, California</th></tr>
<tr><td>Process</td><td colspan="2">Dry</td><td>Dry</td><td colspan="3">Dry</td></tr>
<tr><td>Number of Kilns</td><td colspan="2">3</td><td>2</td><td colspan="3">6</td></tr>
<tr><td>Capacity (000 tpy)</td><td colspan="2">620</td><td>733</td><td colspan="3">1,147</td></tr>
<tr><td>Number of Preheaters</td><td colspan="2">2</td><td>0</td><td colspan="3">1</td></tr>
<tr><td>Kiln Data</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Year</td><td>1959</td><td>1961</td><td>1964</td><td>1948</td><td>1951</td><td>1959</td></tr>
<tr><td>Number</td><td>2</td><td>1</td><td>2</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>Capacity (000 tpy)</td><td>189</td><td>216</td><td>432</td><td>162</td><td>162</td><td>180</td></tr>
</table>

Source: Portland Cement Association - U.S. Portland Cement Industry: Plant Information Summary, December 31, 1974

b. Operating Costs

Table IV-20 shows the estimated cement manufacturing cost at a 1350-tpd cement plant using coal fuel. For purposes of direct comparison, the basis for this estimate is the same as for the base case (Section IV-A).

6. Environmental Aspects

Two major environmental aspects attend the use of coal fuel for the manufacture of portland cement:

- Fugitive coal dust emissions from receiving, storing, and handling the coal; and
- Emissions to air and water of the products from burning coal, particularly the coal ash contained in the cement kiln dust.

a. Fugitive Dust Emissions

Airborne coal particulates will be generated by the receiving and handling of coal. The primary sources of this dust will be during railcar unloading. A water-spray system should satisfactorily eliminate this source. The containment and treatment of rainwater run-off from open coal storage will require suitable grading, diking, and treatment facilities. The treatment of run-off from coal piles where de-icing compounds such as calcium chloride are used will require special attention.

The main points of fugitive coal dust emission and methods for their control are as follows:

- coal transport to and from plant - Rail cars and conveyors probably will have to be covered.
- coal storage piles - Wet pile storage would probably have to be used, or else silos and wind breakers will be employed.
- stacker/reclaimer - The conveyor would be covered and a suitable hood built to enclose the reclaim wheel.
- coal conveyors - Transfers would be fitted with suitable hoods, and conveyors would be covered.
- crushing and screening building - Transfer points would be hooded, building vents would be enclosed and treated.

TABLE IV-20

PORTLAND CEMENT PRODUCTION COST: LONG ROTARY KILN (COAL FIRED)

Product: Type I Portland Cement

Byproducts: None

Annual Capacity: 445,500 tons

Annual Production: 445,500 tons

Process: Long Rotary Kiln Dry Process

Fixed Investment: $\$45 \times 10^6$

Working Capital: $\$2.8 \times 10^6$

Location: U.S. East Coast

Stream Days/Yr.: 330

	Units	Quantity/Ton	Unit Cost	$/Ton
VARIABLE COSTS				
Raw Materials: Limestone		included in other costs		
Argillaceous Compounds		included in other costs		
Gypsum & Minor Additives				1.00
Purchased Energy: Fuel (Coal)	10^6 Btu	4.2	$1.00	4.20
Electric Power	kWh	130	0.02	2.60
Water: Cooling	10^3 gal	0.45	0.03	0.01
Operating Labor	Man-Hour	0.6	6.00	3.60
Labor Overhead		30% of Operating Labor		1.08
Operating, Main. & Repair Supplies		2% of Plant Cost		2.02
FIXED COSTS				
Plant Overhead		70% of Operating Labor		2.52
Taxes & Insurance		2% of Plant Cost		2.02
Depreciation		20 year, straight line		5.05
TOTAL PRODUCTION COST				24.10
Pre-Tax Return on Investment		20%		21.46
TOTAL				45.56

Source: Arthur D. Little, Inc. estimate.

b. Coal Combustion Products

Products of environmental concern from coal combustion are SO_x and coal ash. The sulfur oxides appear to react readily with the alkalies (potassium and sodium) in cement raw materials, as well as the calcium oxide in the raw material in the calcining zone of the rotary kiln, or within the suspension and preheater to form calcium sulfates, and to react with other basic constituents of cement clinker. The operating problems which result from the presence of too much sulfur dioxide in rotary kiln combustion gas has been discussed in detail in section IV-A. However, it appears that the amount of sulfur dioxide in combustion gases emitted from rotary kilns burning coal with a high sulfur content is still extremely low. This has received considerable attention in the past.

To a large extent, the coal ash from rotary combustion contacts and chemically combines with the clinkering raw material within the kiln. However, some of the coal ash escapes from the rotary kiln along with partially calcined raw feed. This combined dust and fine coal ash is removed from the gas by either electrostatic precipitators or glass cloth filters before the combustion gas is emitted to the atmosphere. Depending upon the kind of cement being produced, the nature of the raw material being used, and the design and operation of the clinkering system (i.e., long rotary kiln, suspension preheater, etc.), the collected kiln dust is returned to the kiln, discarded, or both. Rainwater run-off from the typical uncovered storage pile of waste kiln dust contains a high concentration of soluble potassium and sodium sulfate and calcium hydroxide. In addition, iron, aluminum, and magnesium are typical major chemical constituents of coal ash. Because of the thermal history of the coal ash, it is probably present in a glassy or amorphous state; therefore, it is quite highly chemically reactive, especially in the highly alkaline aqueous solution formed by the percolation of rainwater through the dust pile. Any of the many elements present in the coal ash associated with the discarded kiln dust which are soluble in high pH aqueous solutions can and probably will be present in such run-off. The actual elements present in coal ash will depend upon the specifc coal being burned.

The concentration of minor constitutents in the individual raw materials used for making portland cement is expected to vary considerably from plant to plant. The literature contains few exhaustive chemical analyses of waste kiln dust. In one of these (Table IV-21) the typical elements, potassium, sodium, calcium, and sulfur, predominated, as expected. Also, a high concentration of carbonate coming from the limestone which was not calcined is also present. Other elements which form compounds, such as sulfates or oxides with high vapor pressures, were concentrated to a significant extent: e.g., rubidium, zinc, and lead.

TABLE IV-21

TYPICAL COMPOSITION OF DRIED KILN DUST

		Weight %
Clay (HCl insoluble, fired at 800°C)		4.61
Organic substance		2.06
Cations		
Lithium	Li^+	0.0064
Sodium	Na^+	12.25
Potassium	K^+	24.50
Rubidium	Rb^+	0.475
Cesium	Cs^+	0.0074
Magnesium	Mg^{++}	Trace
Calcium	Ca^{++}	9.26
Strontium	Sr^{++}	0.015
Sum of Cations		
Anions		
Fluoride	F^-	0.46
Chloride	Cl^-	1.43
Bromide	Br^-	0.040
Iodide	I^-	0.0552
Carbonate	CO_3^{--}	29.59
Sulfate	SO_4^{--}	9.06
Sulfide	S^{--}	Trace
Borate	BO_3^{---}	0.152
Phosphate	PO_4^{---}	Not detectable
Sum of Anions		

Heavy Metals (Weight %)			Heavy Metal Oxides (Weight %)	
Chromium	Cr	0.011	Cr_2O_3	0.016
Manganese	Mn	0.013	MnO_2	0.021
Iron	Fe	0.84	Fe_2O_3	1.19
Zinc	Zn	1.62	ZnO	2.02
Lead	Pb	0.562	PbO	0.607
Sum of all determinations				97.825
Oxygen (from CaO not bound in carbonate)				2.98
Sum of all constituents				100.805

Source: Davis, T.A. and D.B. Hooks, "Disposal and Utilization of Waste Kiln Dust from Cement Industry", EPA-670/2-75-043, May 1975

c. Coal Impurities

The composition of the coal impurities is important since they form part of the waste dust from a coal-fired cement kiln. The major mineral impurities found in coal, ranked in decreasing order of the amount present, are as follows:

(1) Shale group

- Muscovite
- Illite
- Montmorillonite

(These are principally sodium, potassium, calcium, aluminum, magnesium and/or iron silicates.)

(2) Kaolin group

- Kaolinite (aluminum silicate)

(3) Sulfide group

- Pyrite
- Marcasite

(4) Carbonate group

- Calcite
- Ankerite

(5) Cloride group

- Sylvite
- Halite

The minor minerals that have been identified in coal, roughly in order of decreasing abundance, are as follows:

(1) Quartz
(2) Feldspar
(3) Garnet
(4) Hornblend
(5) Gypsum
(6) Apatite
(7) Zircon
(8) Epidote
(9) Biotite
(10) Augite
(11) Prochlorite
(12) Diaspore
(13) Lepidocrocite
(14) Magnetite
(15) Kyanite
(16) Staurolite
(17) Topaz
(18) Tourmaline
(19) Hematite
(20) Pennitite

Of these 20 minerals, 13 are silicates.

The typical limits of the oxides present in the ash of bituminous coals from the United States are as follows:

Constituent	Percent
Silica (SiO_2)	20-60
Aluminum oxide (Al_2O_3)	10-35
Ferric oxide (Fe_2O_3)	5-35
Calcium oxide (CaO)	1-20
Magnesium oxide (MgO)	0.3-4
Titanium oxide (TiO_2)	0.5-2.5
Alkalies (Na_2O+K_2O)	1-4
Sulfur trioxide (SO_3)	0.1-12

The West Virginia Geological Survey analyzed 596 spot samples for 38 elements from 16 coal beds representing major coal-producing areas of that state (Table IV-22).

TABLE IV-22

COMPOSITION* OF WEST VIRGINIA COAL ASH

Oxide	Average, Percent	Oxide	Average, Percent
Li_2O	0.075	CoO	.010
Na_2O	1.78	Cr_2O_3	.023
K_2O	1.60	CuO	.061
Rb_2O	.030	GaO	.022
CaO	2.76	GeO_2	.011
SrO	.38	HgO	.011
BaO	.22	La_2O_3	.030
MgO	.98	MnO	.046
Al_2O_3	29.9	MoO_3	.016
SiO_2	43.9	NiO	.047
Fe_2O_3	15.9	P_2O_5	.35
TiO_2	1.52	PbO	.048
Ag_2O	.0010	Sb_2O_3	<.005
As_2O_3	<.07	SnO_2	.020
B_2O_3	.12	V_2O_5	.050
BeO	.008	WO_3	<.01
Bi_2O_3	<.004	ZnO	.053
Cb_2O_5	.010	ZrO_2	.029

* Spectrographically determined

Source: Leonard, J.W. and D.R. Mitchell, Editors, "Coal Preparation", 3rd Edition, AIME, 1968

d. Kiln Dust

(1) General

The most significant impacts on the environment of the various effluent streams from a cement plant are associated with, or result indirectly from, the solid particulate matter carried out of the rotary kiln by the exiting combustion gases. The available literature contains little data concerning the quantity and composition of this kiln dust because:

- only during approximately the last 15 years has kiln dust been discarded as a waste material by any significant number of cement plants. Prior to that time, kiln dust was considered a valuable material, representing a considerable amount of processing cost, and was returned to the kiln for conversion into cement clinker.

- The quantity and chemical composition of kiln dust is very variable, and is quite sensitive to the operating conditions of the rotary kiln, and to the nature of the raw material components, as well as to the chemical composition of the raw feed.

The motivation for the disposal of kiln dust was the trend of continually increasing cement compressive strength and steadily declining cement alkali content. The specification for low alkali cement (0.6% total alkalies expressed as Na_2O) is not unusual for major projects such as municipal water facilities, to avoid the destructive alkali-aggregate reaction. These two cement quality characteristics have tended to become widespread among cement users, resulting in cement plants discarding progressively more kiln dust to diminish the alkali content of the finished cement.

(2) Dust Quantity

The quantity of dust carried from a portland cement rotary kiln usually varies from 3% to 40% of the clinker production. Usually, the amount increases directly in accordance with kiln production rate because as the latter increases, the fuel consumption rate must also increase to provide sufficient heat for clinkering. This increased fuel consumption commensurately increases the production of hot combustion gases, consequently resulting in an increase in the kiln gas velocity within the rotary kiln itself. This increased kiln gas velocity, therefore, carries a higher quantity of dust particles from the kiln. As a rotary kiln is operated over its design production capacity, usually the production of kiln dust drastically increases. This interrelationship of processing parameters results in the description of maximum production capacity from any cement rotary kiln, since the collection and return of a rate of dust generation equivalent to more than 40 or 50% of the clinker production rate usually makes operation technically and probably economically undesirable or infeasible.

Therefore, the quantity of dust generated per ton of cement clinker produced by a rotary kiln system, which is being operated at its design capacity, can be set within some reasonable limits.

Technically, kiln dust can be returned to a cement rotary kiln in any one of several ways. The two most common are: (1) addition to the raw material feed going to the rotary kiln feed end; and (2) insufflation. In the latter case, the dust is pneumatically conveyed through a pipe adjacent to and aligned in parallel with the fuel burner pipe in the firing end of the kiln. The incoming cloud of suspended dust particles is rapidly heated and tends to adhere to the coating adhering to the refractory lining of the rotary kiln, as well as to the nodules of clinker.

The recently published results of a survey among 101 cement plants concerning the disposal and utilization of waste kiln dust (Davis, T.A., & D.B. Hooks, "Disposal and Utilization of Waste Kiln Dust from Cement Industry" EPA-670/2-75-043, May 1975) showed that 57 discard some and 16 discard all of the dust which is collected. The most common current method of dust disposal is to simply pile the dust on cement plant property. Between one-third and two-thirds of the total alkalies present in kiln dust are water-soluble, and are continually leached from the dust pile by rainwater. The leachate from such piles typically has a pH in the range of 12-13. It has also been reported that this high pH does not appear to diminish rapidly, since an old pile of kiln dust had rainwater run-off of 12-13 pH even after five years with no new dust additions.

The high pH characteristic of rainwater run-off from waste kiln dust piles is probably in large part due to the calcium hydroxide produced by the hydration of calcium oxide in the dust. Typically, the pH is lowered by either the addition of waste acid to this leachate or by bubbling carbon dioxide through a reservoir of this leachate. The carbon dioxide is conveniently obtained at a cement plant by taking some of the stack gases, which contain a high concentration of carbon dioxide, and sparging them into the supernatent liquor on the surface of a waste kiln dust disposal pond.

(3) Reuse of Kiln Dust

At some cement plants, kiln dust which is discarded because it contains too high a concentration of alkalies is reused after the water-soluble alkali values have been leached by water treatment. Typically, the leaching occurs in a waste kiln dust pond, where the water can be recirculated to the hydraulic conveying system for transporting dust to the pond, until it becomes saturated in alkali salts. Periodically, the leached solids are dredged and reintroduced as an additive to the raw feed, with suitable chemical correction of the raw feed.

(4) Chemical Composition of Dust

The chemical composition of kiln dust varies so widely that it is very difficult to characterize this waste material, or the recycled material. This is one of the reasons that the literature contains very few analyses of kiln dust. In one chemical analysis of the potassium and sodium content of a sample of kiln dust from an electrostatic precipitator, as a function of particle size, the collected sample contained approximately 0.4% Na_2O, and 9% K_2O (Table IV-23). But a complete chemical analysis, including minor and trace elements, is typically not done on kiln dust. A sample of kiln dust which was collected in an electrostatic precipitator at a cement plant in Blaubeuren, West Germany, analyzed by chemical methods and X-ray fluorescence spectroscopy, showed an extremely interesting high concentration of rubidium, zinc, and lead. The high concentration of zinc and lead are probably due to the relatively high vapor pressures of the oxides of these materials.

Depending upon the specific compounds formed in the high-temperature clinkering zone, the rotary kiln gases will contain species of varying vapor pressures (or volatilities) and concentrations. As a result, certain elements will be volatilized to a greater extent than others, and will tend to concentrate in the kiln dust, rather than in the clinker. For example, under the oxidizing conditions present in the high-temperature zone of the rotary kiln, zinc will probably oxidize, and due to the high vapor pressure of zinc oxide, will tend to volatilize, and reform as a fume in the cooler regions of the kiln. Due to the very small particle size of this fume, it will probably be concentrated in the dust collected by the last compartments of the electrostatic precipitator. Also, the alkali family of elements, potassium, sodium, rubidium, etc., will tend to be concentrated in the kiln dust rather than in the clinker due to the formation of sulfates and chlorides of these elements; and the high vapor pressures of these compounds will tend to concentrate these elements in the kiln dust.

TABLE IV-23

PARTICLE SIZE ANALYSIS AND DISTRIBUTION OF ALKALIES IN A SPECIMEN KILN DUST FROM AN ELECTROSTATIC PRECIPITATOR

Particle Size Range (Microns)	Weight Percent	Total Alkalies (%)		Water Soluble Alkalies (%)		Water Insoluble K_2O (%)
		Na_2O	K_2O	Na_2O	K_2O	
+68	0	-	-	-	-	-
-68+48	0.3	0.30	3.62	*	*	-
-48+34	0.4	0.31	3.46	*	*	-
-34+24	0.7	0.35	4.51	0.094	1.927	2.58
-24+17	1.8	0.38	5.08	0.117	2.560	2.52
-17+12	5.1	0.40	5.15	0.134	3.072	2.08
-12+6	27.3	0.33	5.35	0.134	3.252	2.10
-6	64.4	0.42	10.72	0.242	8.191	2.53

* Insufficient sample for analysis

Source: Davis, T.A. and D.B. Hooks, "Disposal and Utilization of Waste Kiln Dust from Cement Industry"; EPA-670/2-75-043, May 1975

e. Water Pollution

A coal-fired cement plant of the same capacity (1350 tpd) and general process configuration as the base case will produce a cooling water wastewater stream and a dust storage pile run-off stream of exactly the same size and composition as that of the base case cement plant. (See Appendix C.)

However, an additional wastewater stream must be dealt with: i.e., run-off water from the coal storage area. The composition of coal pile run-off water can vary greatly, but generally the water tends to be slightly acidic and may contain a variety of sulfur compounds and leached heavy metals. The generally recommended form of treatment consists of clarification with lime, which is intended to neutralize the water, remove suspended solids, and precipitate heavy metals. The coal pile storage area will be about 33,000 ft^2. Unlike discarded dust, which is often left in a pond partially filled with water, the coal pile must be maintained in a relatively dry condition. Thus, all run-off from the area must be collected and treated; it cannot be allowed to accumulate. The coal pile run-off wastewater collection and treatment system must therefore be sized for the total annual precipitation, not just precipitation in excess of evaporation. For the purpose of cost estimates, we used a rainfall rate of 30 inches per year, which amounts to an average flow rate of 17,000 gpd. To contain surges from heavy storms a substantial surge capacity must also be provided.

Because of the need to treat coal pile run-off, the treatment cost (Table IV-24) is substantially higher than that of the base case cement plant: $0.75/ton vs $0.45/ton.

TABLE IV-24

WASTEWATER TREATMENT COSTS: COAL FIRING

Basis 1350 tpd Cement Production
330 Operating Days Per Years

CAPITAL INVESTMENT - $931,000

	Annual Quantity	Cost Per Unit Quantity	Quantity Per Ton of Production	Unit Cost ($ Per Ton of Product)
VARIABLE COSTS				
Operating Labor (including overhead)	3075 man-hr	$12/hr	0.007	0.0828
Maintenance (including Labor & Mtls)				0.0836
Chemicals				
Sulfuric acid	14 tons	$100/ton	$3.1\text{x}10^{-5}$	0.0034
Lime	1 ton	$100/ton	$2.2\text{x}10^{-6}$	
Electrical Power	365,000/ kWh	$0.02/ kWh		0.0164
TOTAL VARIABLE COST				0.1862
FIXED COST				
(Depreciation @ 5%)				0.1045
(Taxes & Insurance @ 2%)				0.0418
TOTAL FIXED COST				0.1463
TOTAL ANNUAL COST				0.3325
RETURN ON INVESTMENT @ 20%				0.4180
TOTAL				0.75/ton

Notes:

1) Capital investment adjusted to 1975 level (ENR Construction Cost Index = 2126)

2) Wastewater treatment includes:

   a) Non-contact cooling water thermal pollution control via spray pond
   b) Dust pile runoff containment, collection, clarification, and neutralization
   c) Coal storage pile runoff containment, collection, lime precipitation and clarification

3) Estimates are for the specific example of a dry-process, non-leaching cement plant, and are in no way intended to represent industry-wide wastewater treatment costs.

Source: Arthur D. Little, Inc. estimates

V. IMPLICATIONS OF POTENTIAL INDUSTRY/PROCESS CHANGES

A. SUSPENSION PREHEATER AND FLASH CALCINER

1. Environmental and Energy Impact

The suspension-preheater-equipped rotary kiln requires less heat energy, of fuel, per ton of cement clinker produced than any other commercially available clinkering step. Although the flash calciner may have a slightly lower energy requirement, both of these process alternatives to the long rotary kiln are reported to be very similar in thermal energy requirements. It also appears that the suspension preheater or flash calciner represents the lowest total energy (i.e., combined electrical and fuel energy) required for producing portland cement of any of the commercially available process alternatives.

Neither the suspension preheater nor flash calciner appear to present any new dimension to the environmental aspects of the manufacture of portland cement. In fact, when these processes are operated on suitably low alkali raw materials, and with suitably low sulfur fuels the present state-of-the-art employs total dust recycle, which eliminates the environmental problems associated with disposal of waste kiln dust. In addition, the flash calciner appears to produce combustion gases with a significantly lower NO_x content than either the suspension preheater or the long rotary kiln.

2. Systems Implications

An important overall (systems) implication of the use of the flash calciner is that significant quantities of high-temperature gases are available for drying raw materials. The temperature of these gases is typically higher than can be used with a conventional closed-circuit ball mill raw material grinding system. However, the roller mill is gaining rapid and wide acceptance for raw material grinding. This new mill can be operated with these high-temperature gases and can utilize their additional drying capacity to help grind raw materials of significantly higher moisture content. The roller mill is reputed to grind raw materials for cement making with a 25-35% raw grinding energy savings.

3. Probability of Change

The acceptance of the suspension preheater process alternative is widespread throughout the world, and has recently risen to a high level in the United States. It appears that the U.S. cement industry will continue to move from the wet to the dry process, and toward the suspension preheater in the latter.

Although the flash calciner has been totally accepted in Japan and in much of Europe, the U.S. cement industry appears to be waiting for a demonstration of satisfactory performance by its first flash calciner, which is presently being completed in the United States.

One of the major advantages of the flash calciner is the extremely high output of a moderate-sized rotary kiln, which permits the construction and successful operation of extremely large cement plants--possibly as high as 10,000 metric tons per day capacity--with rotary kiln sizes which are small enough to insure good performance. One of the reasons for its wide acceptance in Japan is that the Japanese cement market is geographically distributed to favor such very large single cement plants.

However, in the United States, cement plants of 2,000- to 3,000-tpd capacity are typical. Therefore, the advantages which derive from the use of the flash-calciner-equipped rotary kiln may not be sufficiently great in the United States to cause it to be favored this strongly over the suspension preheater. The roller mill for raw material grinding effectively combines with the flash calciner. Other key aspects of the flash calciner are its significantly lower NO_x emissions, better refractory life, and apparently slightly lower fixed capital investment (and probably slightly lower operating costs) as well. These aspects along with the ability of the flash calciner to operate on raw materials containing fuel values such as oil shale will probably motivate other cement manufacturers to install this newest process alternative to the long rotary kiln.

B. FLUIDIZED-BED CEMENT PROCESS

1. Environmental and Energy Impact

No commercial installations of the fluidized-bed cement process are operating, or have ever been constructed. A 100-tpd semi-commercial fluidized-bed facility was successfully operated for several years. This process is presently offered by two U.S. firms. It appears that the total energy required for the manufacture of cement by this process is about 10% more than that required for cement manufactured by the four-stage suspension-preheater-equipped rotary kiln, and is therefore potentially directly competitive with the suspension preheater system which is rapidly assuming the preeminent position of standard process technology in the international portland cement community.

The fluidized-bed cement process also appears to emit extremely low levels of particulates compared with a rotary kiln, and these particulates are essentially all water-soluble alkali sulfates. This holds the promise of eliminating large landfill or storage pond areas for the satisfactory and environmentally acceptable disposal of waste kiln dust. In fact, these alkali sulfates could be valuable byproducts from cement manufacture, and could possibly be sold for their potash value.

Due to the exceptionally high alkali volatilization characteristics of the fluidized-bed process, waste kiln dust from conventional rotary kiln cement manufacturing operations (high in alkali) can form either a main raw material component or the total raw material (suitably adjusted in chemistry to make cement clinker) for the fluidized-bed cement process. Therefore, an existing cement plant, which must discard waste kiln dust in order to produce satisfactory cement quality, could operate a fluidized-bed cement process to convert the waste kiln dust from the rotary kiln operations into acceptable cement, thereby drastically reducing or totally eliminating the environmental aspects associated with the disposal of waste kiln dust.

2. Systems Implications

The fluidized-bed cement process is a total departure from any of the other clinker-producing cement process alternatives. Its economic viability rests on heat recuperation from the hot combustion gases leaving the reactor, at least in part, in the generation of steam. This steam could be used directly through turbine drives, or indirectly through the generation of electrical power, to supply all of the electrical energy requirements for the rest of this cement plant (e.g., raw material and finish cement grinding, and supply of fluidizing and combustion air at suitable pressure).

Several decades ago, the utilizing of waste heat from rotary kiln plants was accomplished through the generation of steam for electrical power production. This was ultimately abandoned due to the high operating and maintenance costs associated with cleaning the resulting raw material and alkali sulfate deposits which developed rapidly on the tubes, as well as the problems associated with maintaining and operating electrical generating equipment at plant sites with high particulate concentrations in the ambient air. The generation of steam associated with the fluidized-bed cement process is totally different, in that the high-temperature gases leaving the fluidized-bed reactor could generate high-pressure steam, rather than the low-pressure steam associated with true waste heat boiler operation of old cement plants. In addition, it is reported that the concentration of particulates in this high-temperature gas is very low compared with rotary kiln waste gas, which permits the development of non-fouling boiler tube and steam generating designs. In fact, it is reported that the fluidized-bed cement process could generate more electrical energy than is required by a cement plant, and such a cement plant could be a supplier of electrical energy to the power grid, rather than a consumer of electrical energy. The widespread acceptance of the fluidized-bed cement process would therefore have a major impact upon energy generation and transmission patterns and demand upon power generating stations.

3. Probability of Change

The first successful production of portland cement in a rotary kiln in the United States was achieved in 1890. Since then, the rotary kiln has grown in diameter, length, and production capacity up to a giant kiln 27 feet in diameter and 700 feet long which has a production capacity of 1.2 x 10^6 tpy.

For decades, the rotary kiln was the only technically sound way of continuously producing portland cement clinker on a relatively large scale and with good quality control. Because of this century-long history of development, the cement rotary kiln has been firmly entrenched as the primary clinkering alternative technology.

The suspension preheater process alternative to the long rotary kiln was commercially accepted approximately 18 years after it was developed. Interestingly, the fluidized-bed cement process was developed about 17 or 18 years ago. It does appear that the U.S. cement industry is seriously considering the fluidized-bed cement process, at least initially as a process alternative for converting waste kiln dust from rotary kilns into marketable cement. We believe that the first commercial-scale, fluidized-bed cement process will be commissioned in the very near future, probably within 5 years.

Another major resistance to the adoption of this process alternative to the rotary kiln, is that the main technology which constitutes this process alternative is foreign to the cement industry, even though the chemical process industry at large has employed large, high-temperature fluidized-bed reactors for decades. We believe that the recent engineering design studies and commercial offering of the fluidized-bed cement process by Scientific Design within the past year are a significant new motivating factor in the consideration and acceptance of this new process technology by the U.S. cement industry.

C. CONVERSION TO COAL FUEL FROM OIL AND NATURAL GAS

1. Environmental and Energy Impact

The energy conservation potential of the use of coal fuel is primarily one of form rather than quantity of energy. The energy required to transport, handle, and pulverize coal for suitability of combustion in cement manufacture may be different from the energy associated with the transportation and use of oil or natural gas, but we believe the difference will be insignificant.

The environmental effects of the switch to coal, however, will be primarily the fugitive dust emissions from the handling and storage of coal, which will have to be suppressed to comply with air pollution regulations. In addition, the rainwater run-off from outdoor coal storage will contain some particulates and also soluble de-icing compounds used in northern latitudes to prevent freezing of coal storage piles. This will have to be collected and treated.

However, the coal ash from the combustion of coal and the manufacture of cement is an additional raw material component and chemically and physically combines with the clinkering raw materials to form cement. Therefore, this market for fly ash converted to the form of cement will tend to offset any increase in energy required by the use of coal.

2. Systems Implications

There appear to be no noteworthy systems implications of the conversion of fuel form to coal.

3. Probability of Change

The probability of conversion to coal fuel is extremely high, as evidenced by the actual conversion from natural gas and oil to coal fuel by cement plants in the United States. The major constraints upon the rate at which this conversion will occur are as follows:

- availability of sufficient coal of appropriate quality;
- sulfur content of available coal - although cement raw materials absorb all of the SO_2 from the combustion of high sulfur coal, if the sulfur level of the coal becomes too high, severe operating problems occur with suspension preheaters and flash calciners, as well as unacceptable chemical and physical characteristics of the finished cement;
- availability of suitable coal pulverizing and handling systems and equipment.

APPENDIX A

BASE LINE CEMENT TECHNOLOGY

1. FEEDSTOCKS

Hydraulic cement is a powder made by burning lime, silica, alumina, iron, and magnesia together in a kiln and then pulverizing the product. It reacts with water to bond rock or sand and gravel into concrete. During 1973, 139 x 10^6 tons of raw materials were used to manufacture 85 x 10^6 tons of cement; i.e., 1.6 tons of raw materials are needed to produce 1 ton of cement. Weight is lost during calcination in the kiln when moisture, carbon dioxide, and other gases are driven off.

In making cement, more limestone is used than any other raw material (Table A-1) since it provides one of the key materials in cement manufacture--lime (CaO). Other sources of lime include shells. Areas bordering the Gulf of Mexico and San Francisco Bay provide oyster shells, while in Florida coquina shells are used. Recently, oolitic aragonite sands from the Bahamas added another source of lime. Occasionally, slag and other industrial wastes rich with lime have been used in cement manufacture. Natural argillaceous limestones known as cement rock are found in the Lehigh Valley in Pennsylvania. These deposits contain the correct amount of all cement making raw materials so that no other material needs to be mixed in. Marls are accumulations of calcareous material secreted by plants or animals in lakes and marshes; they are important in Michigan and Ohio.

When alumina and silica are not present in the limestone in sufficient amounts, secondary raw materials are needed to supply the balance. The ratio of silica and alumina has to be controlled closely. Natural sources of silica include sediments, i.e., sand, silt, clay and loess, or their corresponding rocks, i.e., sandstone, siltstone, shale, or mudstone. Alumina sources include mud, clay, loess and related rocks and wastes, such as fly ash, slag, red muds from bauxite processing and wash plant or mill tailings. Coal fly ash can contribute significant amounts of raw materials.

Iron is sometimes added in small amounts to adjust the composition of the cement mix. Commonly used sources are iron ores, mill scale, and certain metallurgical process waste slags. In recovering these mineral raw materials, the tonnage of overburden handled each year may equal the amounts of raw materials used.

TABLE A-1

TYPES AND QUANTITIES OF RAW MATERIALS USED IN PRODUCING PORTLAND CEMENT IN THE UNITED STATES[1], 1972-1973
(Thousand tons)

Raw Materials	1972	1973
Calcareous:		
Limestone (includes aragonite)	84,922	86,699
Cement rock (includes marl)	25,879	26,067
Oyster Shell	5,081	5,144
Argillaceous:		
Clay	8,062	7,931
Shale	4,096	4,099
Other (includes staurolite, bauxite, aluminum dross, pumice, and volcanic material)	110	240
Siliceous:		
Sand	1,993	2,053
Sandstone and quartz	781	748
Ferrous:		
Iron ore, pyrites, millscale, and other iron-bearing material	839	968
Other:		
Gypsum and anhydrite	4,094	4,253
Blast furnace slag	759	682
Fly Ash	271	299
Other	33	5
Total	136,920	139,188

* Includes Puerto Rico

Source: U.S. Bureau of Mines, Minerals Yearbook

2. PROCESSING

Processing of raw materials into finished cement follows four steps:

- Crushing
- Grinding
- Clinkering
- Finish grinding

a. Crushing

The first step is simply size reduction. Depending on the raw material and the design of the raw grinding system, the crushing system can vary considerably. In the usual case with limestone, crushing produces material at a given maximum size, which typically varies from 3/8 to 2-1/2 inch in diameter. Primary, secondary, and often tertiary crushing stages produce the product for the mills.

The types of crushers used vary according to the hardness, size, and type of the rock. Primary crushers include gyratory crushers, which consist of a steel cone moving eccentrically inside a cone-shaped housing; jaw crushers, in which the rock is broken between substantially vertical moving breaker plates; and roll crushers, where the reduction takes place between two rolls, which often have case-hardened steel teeth, or between one roll and a breaker plate. Typically, primary crushers reduce the rock from shovel size to 5 inch in diameter, while secondary crushers then reduce the rock to 3/4 to 2-1/2 inch in diameter. Secondary crushers include hammer mills in which the rock is fractured by heavy hammers swung by centrifugal force from a horizontal shaft. The crushed stone is then transported by elevator and belt conveyors for storage in separate compartments by raw material type (limestone, shale, etc.).

b. Raw Grinding

Through milling, sizes and mixtures of raw materials are prepared. Not all raw materials can feed directly into grinding mills, especially wet raw materials like clays and chalks which first require disintegration in wash mills where a slurry containing about 50% water is formed. This wash mill product, known as a clay slip, is then fed into wet mills with the roughly proportioned amounts of limestone and other raw materials. The first wet mill stages are commonly ball mills, which get their name from the thousands of large steel balls inside them which are carried on ribs up one side of the rotating mill and cascaded down onto the materials being ground. The second stage of grinding occurs in tube mills, which are similar to ball mills but are longer, of smaller diameter, and charged with smaller balls. Often ball and tube mills are combined into a single machine which has two or three compartments separated by perforated steel diaphragms and charged with differently-sized grinding balls.

Wet milling produces a slurry of the ground kiln feed in which the water content is kept as close as possible to the minimum that can be pumped successfully, i.e., 30-45%. Coarse fractions are returned to be ground again while the finished fractions are pumped to storage tanks or basins for blending. Sedimentation in the tanks is prevented by constant agitation, either mechanically or with air.

The dry milling is very much like the wet except that no water is added and the material is ground dry, usually at 1% moisture content or less. When necessary, dryers are used, supplied with either their own heat sources or recuperated kiln heat. The variety of mills is greater in dry process plants, which in addition to ball and tube mills, use vertical, roller and ball-race mills. Air separators classify the milled product and return the coarse fraction to the milling system. The finished fractions are then blended and homogenized before going to the kiln. It is common practice to combine drying and raw grinding in a single, closed-circuit ball mill system.

c. Clinkering

In the clinkering step, the accurately controlled mixture of raw materials reacts chemically at high temperatures in the kiln to produce clinker, which is subsequently ground into cement. The kiln is the heart of the cement plant; thus, any plant capacity changes reflect changes in kiln capacity.

Briefly described, rotary kilns are nearly horizontal steel cylinders which range up to 25 ft in diameter and 750 ft in length. Inside, the kiln is lined with refractories to protect the steel shell and conserve heat. The inclination of the kiln together with its rotation at rates near one revolution per minute causes the kiln feed to move gradually down the kiln toward the lower, discharge end in several hours.

The burner is at the discharge end. Thus, the flame is pointed in a direction opposite to the feed move direction. As the feed travels toward the firing end, it gets progressively hotter. At first, the heat causes water to evaporate; then it causes carbon dioxide to be driven off during calcination of the carbonates. As the feed approaches the discharge end, it enters the hottest zone, with temperatures about 2,800°F, where the main chemical reactions of hot lime with silica, alumina, and iron begin causing clinker to form. While the size of clinker ranges greatly, a typical range is "buckshot" to "golf ball" size.

Many kilns use chains to improve the heat exchange between the hot gases and feed as they move towards the burning zone. The combustion gases pass through the kiln countercurrent to the material and leave the kiln through its feed end at temperatures between 600° and 1,600°F, depending on the kiln length and the process used.

Formerly, exit gas temperatures from dry process kilns were so high that waste heat boilers were used to generate all the electric power used in the cement plant. But the cost of such a system increased more rapidly than the cost of purchased power. Besides, most new kilns have low exit gas temperatures, thus making purchased power more attractive.

Typically, wet process kilns are designed to be longer than dry kilns since part of the kiln is used to evaporate the raw feed slurry water. Such kilns are equipped with elaborate arrangements of chains which serve as heat exchangers between the gas stream and slurry.

After leaving the kiln, the clinker enters coolers which reduce its temperature before storing or grinding and recover its heat for reuse inside the kiln. There are numerous ways for cooling clinker, ranging from primitive pits to highly sophisticated forced air-cooled reciprocating grate units. These grate units permit a blast of cooling air to pass through a slowly moving bed of hot clinker. When air quenching is used, often the clinker quality is improved because the magnesia freezes into the glass phase in the clinker. Slow cooling could permit the magnesia to crystallize, producing delayed expansion and cracking in the final concrete. Other types of coolers include rotary coolers, which are separate cylinders located under the kilns, and planetary coolers, which consist of smaller cylinders built around, and thus rotating with, the kiln.

d. Finish Grinding

Beyond the cooler, clinker generally is moved by cranes or conveyors into storage, where it is segregated, tested, blended, and moved into bins for feeding to the finish grinding mills. The resulting quality of the cement product varies with the type of storage and time of grinding. Typically, 3-6% gypsum is interground with clinker to control the setting time of the final concrete.

The mills used in finish grinding are essentially the same as those used in raw grinding. Rod, ball, roller, race, and tube mills are found in various finish-grinding installations. Most finish-grinding systems are closed-circuit systems in which air separators provide classification. Fine finished products are sent to storage while coarser fractions are returned for further grinding.

3. PRODUCTS

Superficially, cement seems to be a one-product industry, but the products are more complex. Different cement types are distinguished by (1) their proportions of lime, silica, alumina and iron and (2) the specifications which they meet.

Of all the hydraulic cements, more portland cement is produced than any other cement. Five types are recognized in the United States:

Type I:	For use in general concrete construction;
Type II:	For use in general concrete construction exposed to moderate sulfate action, or where moderate heat of hydration is required;
Type III:	For use when high early strength is required;
Type IV:	For use when a low heat of hydration is required; and
Type V:	For use when high sulfate resistance is required.

These five types can be modified or combined with other materials to qualify for different uses. To act as buffers against freeze-thaw deterioration, air-entraining agents can be interground with the clinker to produce the "A" varieties of cement (mainly, IA, IIA, and IIIA).

A number of cements sold under specifications are known by names which describe their use or composition, including (Table A-2):

- Masonry Cement, which is used in mortars for masonry work;
- Oil-Well Cement, which is designed for use under high temperature and pressure;
- White Cement, which is ordinary portland cement with a low proportion of iron oxide so its color is white instead of grey;
- Water-Proof Cement, which is designed for stucco work and to improve water impermeability;
- Portland-Pozzolan Cement, which is produced by grinding together portland cement clinker and a pozzolana (a material capable of reacting with lime in the presence of water at ordinary temperature to produce cementitious compounds);

TABLE A-2

TYPES OF PORTLAND CEMENT SHIPPED IN THE UNITED STATES 1974*

	Quantity 10^3 ton	Value ($)	Average Value ($/ton)
General use and moderate heat (Types I and II)	73,474	1,927,557	26.23
High-early-strength (Type III)	2,596	71,423	27.51
Sulfate-resisting (Type V)	323	8,653	26.79
Oil-well	989	27,667	27.97
White	474	26,697	56.32
Portland-slag and portland pozzolan	672	16,843	25.06
Expansive	132	4,681	35.46
Miscellaneous**	822	24,385	29.67
Total or average	79,482	2,107,906	26.52

*Includes Puerto Rico

**Includes waterproof cement

Source: U.S. Bureau of Mines, Minerals Yearbook Preprint 1974

- Portland Blast Furnace Slag Cement, which is produced by grinding together a portland cement and granulated blast furnace slag.

Portland blast furnace slag cement usually contains 35 to 45% by weight of granulated slag. This slag is produced by rapid quenching in water and air of hot slag near 2,500°F as it comes from the furnace. Because of the rapid cooling, a glass forms that chemically resembles a low lime clinker, yet it is cheaper.

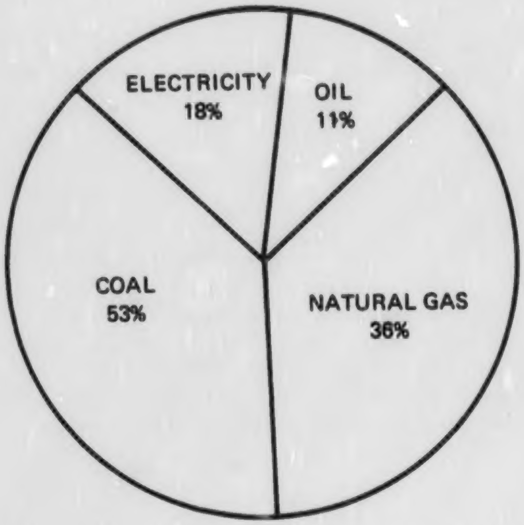
APPENDIX B

BASE LINE PROFILE OF ENERGY USE IN THE CEMENT INDUSTRY*

1. TOTAL ENERGY

In 1974, the U.S. hydraulic cement industry consumed more than 490 x 10^{12} Btu of fossil fuels and about 11 x 10^9 kWh of electricity, which is about 1% of all energy used in the United States. To produce one ton of cement, the average cement plant used 6.3 x 10^6 Btu of fuel and 134 kWh of electricity. The cost of this energy represented about 40% of the production cost.

The cement industry uses all forms of energy: coal, fuel oils (distillates and residual oils), natural gas, and electricity. The consumption of coal and natural gas is about equal (Figure B-1).



Source: Arthur D. Little and U.S. Bureau of Mines

Figure B-1. Types of Energy Used by the U.S. Portland Cement Industry, 1974

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*The U.S. Bureau of Mines is cited throughout this Appendix as a source. In all cases our information has come either from their Annual Mineral Yearbook or Monthly Cement Industry Survey.

a. **Fuel**

Almost 25% of all clinker is produced in 42 coal-fired plants (Table B-1). Nearly 22% more of the total clinker production is produced in plants fired solely by natural gas or oil. The remaining clinker is produced in 89 cement plants, fired by a combination of fuels: coal and oil, coal and natural gas, oil and natural gas, and coal, oil, and natural gas.

From 1950 to 1960, the use of coal declined rapidly while the use of natural gas simultaneously increased (Figure B-2). Between 1960 and 1969, the use of coal, oil, and gas leveled off. In 1970, the use of natural gas took the lead, oil use increased dramatically, and coal use fell off. In 1971, natural gas use peaked and then started its present decline. Meanwhile oil use increased until 1973, when price and availability caused coal use to increase.

TABLE B-1

CLINKER PRODUCED IN THE U.S. BY KIND OF FUEL, 1974

		Clinker Produced		Fuel Consumed		
Fuel	Number of Plants	(10^3 ton)	(percent of total)	(10^3 ton)	(10^6 cf)	(bbl)
Single Fuel						
Coal	42	19,298	24.8	4,724	-	-
Natural Gas	27	10,980	14.1	-	70,246	-
Oil	10	5,801	7.4	-	-	5,465
Multiple Fuels						
Oil and Natural Gas	31	15,313	19.6	-	74,843	1,902
Coal and Natural Gas	33	12,950	16.6	1,516	47,331	-
Coal and Oil	16	8,465	10.9	1,367	-	2,604
Coal, Oil, Natural Gas	9	5,170	6.6	487	15,962	339
TOTAL		77,977	100.0	8,094	208,382	10,310

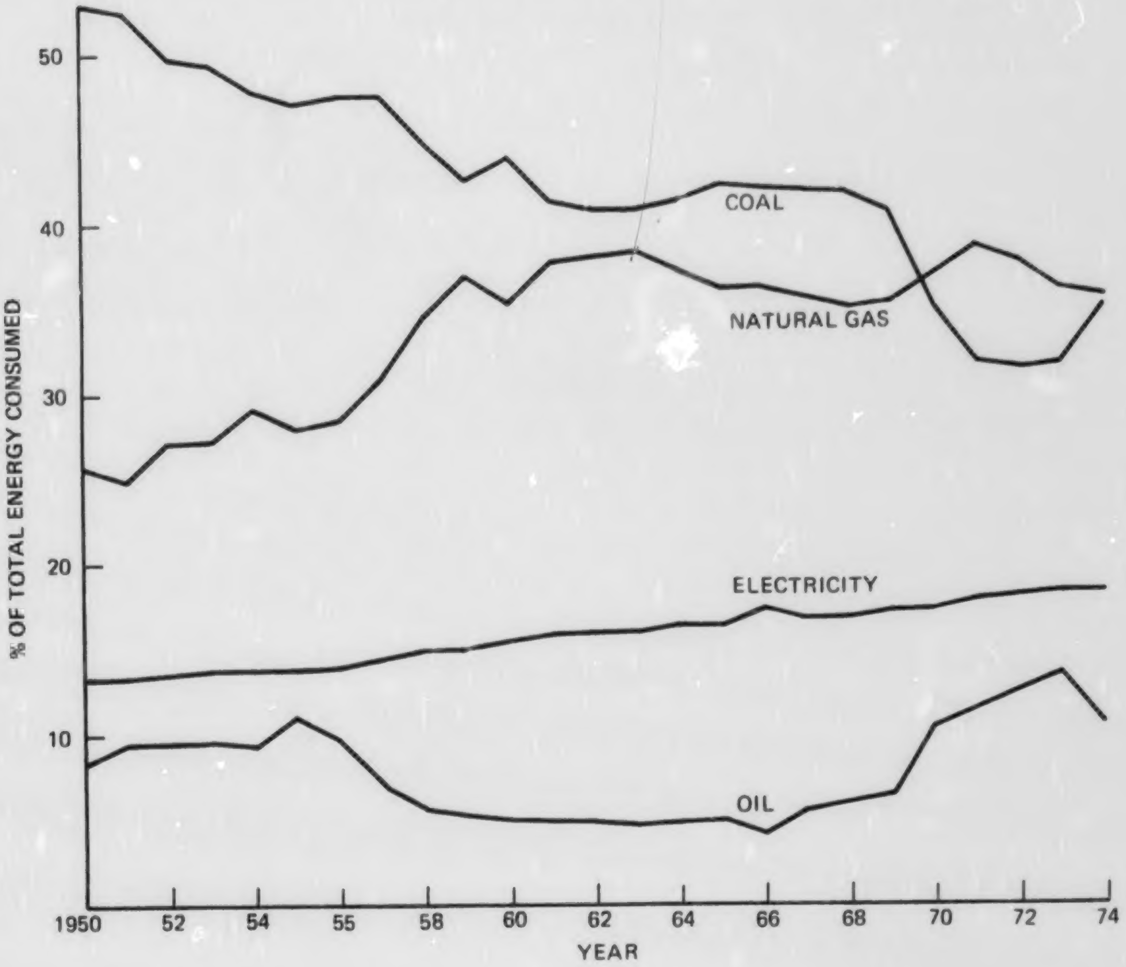
Note: Includes Puerto Rico

Source: U.S. Bureau of Mines

b. **Electric Energy**

In 1974, of the total energy consumed in cement manufacture, 18% was electricity of which 94% was purchased and 6% was generated by cement plants (Table B-2)

The wet process produced 57.5% of the cement but consumed only 54.6% of the total electricity. Since 1950, total electricity used to produce one ton of cement has increased, since cement is being ground finer (Figure B-3).



Source: U.S. Bureau of Mines and Arthur D. Little, Inc.

Figure B-2. Trends in Types of Energy Used, 1950-1974

TABLE B-2

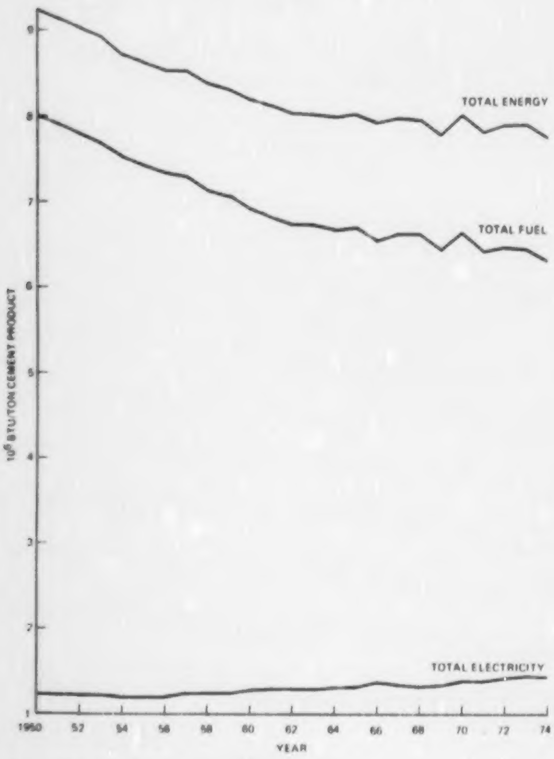
ELECTRICAL ENERGY USED IN PORTLAND CEMENT MANUFACTURE, 1974
(10^6 kWh)

	Generated	Purchased	Total	Electricity Use/Ton Cement
Wet	135	5,700	5,835	127.6
Dry	499	3,938	4,437	142.9
Both	11	401	412	151.6
TOTAL	645	10,039	10,684	134.4*

*Equivalent to 1,411,000 Btu/ton (based on 10,500 Btu/kWh)

Note: Includes Puerto Rico

Source: U.S. Bureau of Mines



Source: U.S. Bureau of Mines

Figure B-3. Trends in Fuel and Electricity Use, 1950-1974

2. ENERGY USE BY PROCESS

Of all processes, the one using a preheater consumes the least energy. As shown in Table B-3, the preheater dry or wet process consumes 4.3 x 10^6 Btu/ton cement versus 5.7 x 10^6 and 6 x 10^6 Btu/ton for the dry and wet processes respectively. For all processes the clinkering step consumes the most energy, with an average of 80% of the total energy used, most of which is fossil fuel. Most electricity, on the other hand, is used in grinding.

a. Grinding

Whether or not the grinding is raw or finish, less energy is consumed in the wet process than either the dry or preheater process. In the wet process, 98 x 10^3 Btu/ton of cement are consumed in raw grinding and 197 x 10^3 Btu/ton of cement for finish grinding compared with 15 x 10^3 Btu/ton and 215 x 10^3 Btu/ton for the dry and preheater processes. The Portland Cement Association has reported a range or raw grinding, in Btu equivalents of purchased electric energy, of 9.7-226 Btu/ton clinker and 86-240 Btu/ton clinker for finish grinding.

TABLE B-3

ENERGY USE BY PROCESS STEP
(10^3 Btu/ton Cement)

Process Step	Wet	Dry	Preheater
Quarrying-Electric	8	6	6
-Fuel	16	16	16
Crushing and Drying			
-Electric	9	15	15
-Fuel	--	600	600
Raw Grinding-Electric	98	126	126
Mixing Feed-Electric	7	14	14
Clinkering and Cooling			
-Electric	86	94	112
-Fuel	5,560	4,600	3,200
Finishing Grinding-Electric	197	215	215
Pack Handling-Electric	15	14	14
TOTAL	5,996	5,700	4,318

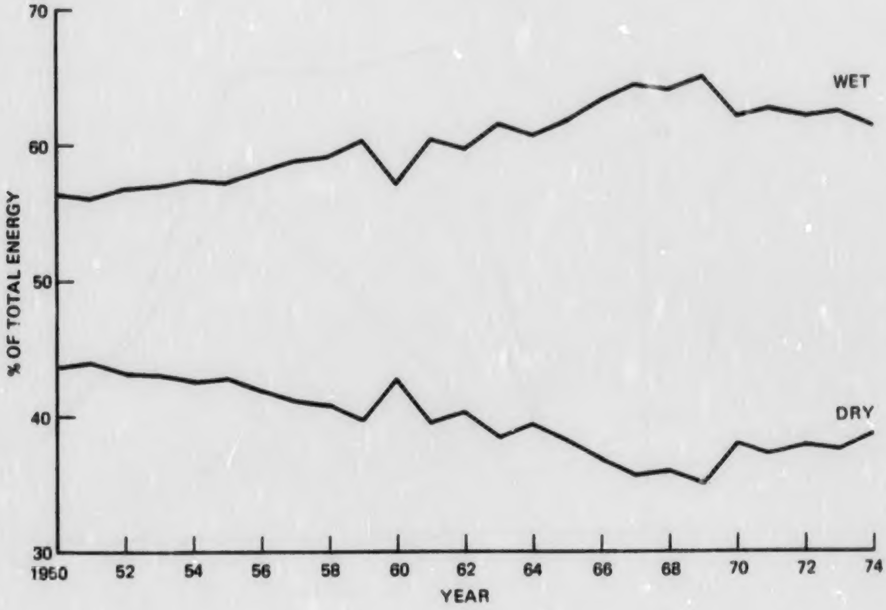
Source: Garrett, H.M. and J.A. Murray, p. 76, Rock Products, May, 1974

b. Clinkering

Energy consumption in clinkering varies according to type of kiln. In 1974, the wet process consumed 61.3% of the total energy consumed in cement manufacture, yet it contributed only 57.9% of the total clinker produced. The dry process, on the other hand, consumed 38.7% of the total energy to produce 42.1% of the total clinker (Figure B-4). Since 1950, the wet process has been consuming a greater percentage of the total energy. Starting in 1950, the wet process consumed 56% of the total, peaking at a high percentage of almost 65% in 1969. This difference was also reflected in the dry process, which dropped in energy use. After 1969, energy use in the wet process leveled out at around 62.1% (still above the 1950 level) as the dry process simultaneously leveled out at around 37.9%.

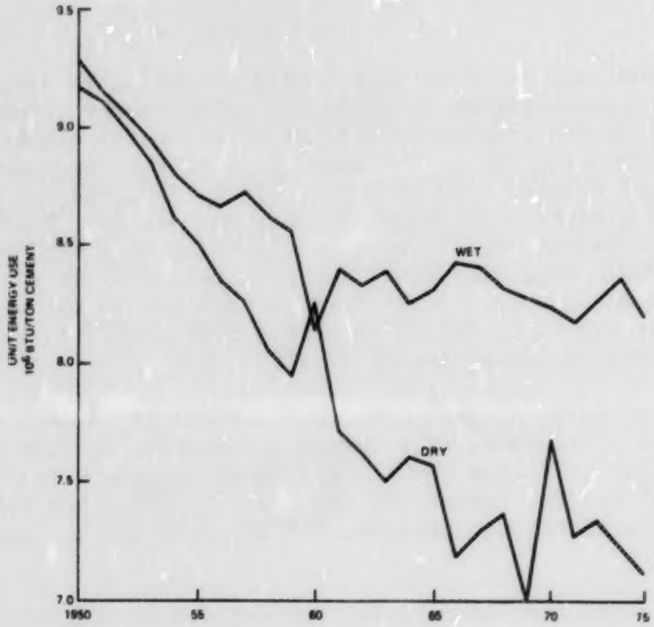
The trends in unit energy use for the wet and dry processes are more dramatic (Figure B-5). In 1950, unit energy consumption for the two processes was within 1%, that is 9.29 x 10^6 Btu/ton cement produced for the wet process versus 9.18 x 10^6 Btu/ton cement for the dry. By 1974, the spread in values increased to 13% with the wet process at 8.21 x 10^6 Btu/ton and the dry at 7.13 x 10^6 Btu/ton

Figure B-6 shows the distribution for wet and dry plants. Although not indicated on the figure, there were three wet and dry plants in 1974, one which consumed less than 6 x 10^6 Btu/ton, one which consumed 8.1-9.0 x 10^6 Btu/ton, and one which consumed 9.1-10.0 x 10^6 Btu/ton.



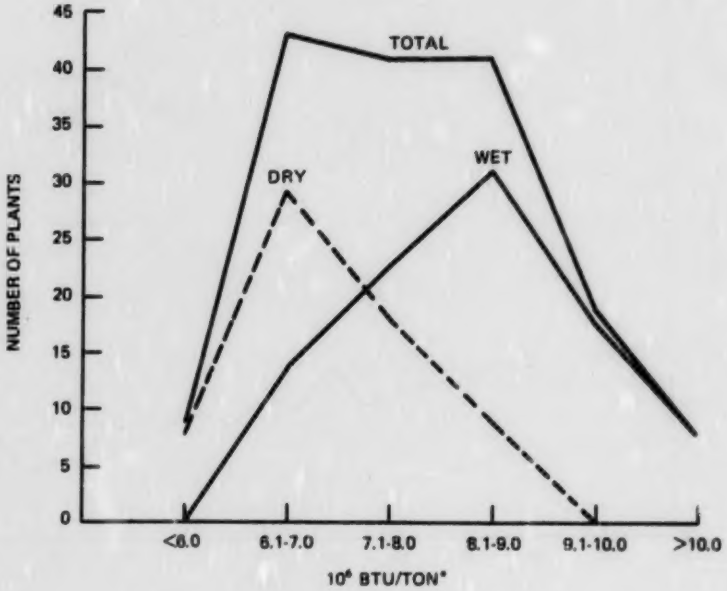
Source: U.S. Bureau of Mines

Figure B-4. Trends in Energy Consumption by Process Step, 1950-1974



Source: U.S. Bureau of Mines

Figure B-5. Trends in Unit Energy Use For Wet and Dry Processing, 1950-1970



*TONS OF EQUIVALENT PRODUCTION (92% CLINKER AND 8% CEMENT)

Figure B-6. Distribution of Unit Energy Consumption by Number of Plants, 1974

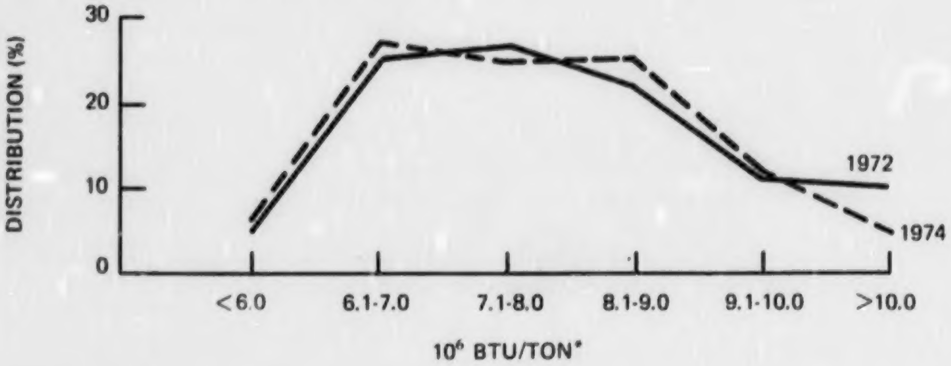
Compared with 1972, the percent unit energy consumption shifted by 1974, when only 17% of the plants used over 9 x 10^6 Btu/ton, down from 21% in 1972 (Figure B-7).

c. Energy Efficiency

Energy efficiency varies according to plant age and size (Table B-4). On the whole, older plants consumed 21% more energy than newer plants. Now, only 13% of the cement plant capacity is 40 years old or older. By 1984 this figure will rise to 30% or more, assuming the same rate of replacement.

With plant size, the larger the plant the more energy-efficient it is. For all plants the difference in energy efficiency for small and large plants is 14%, but for wet plants the difference can be as much as 17% compared with 7% for dry plants. Ideally, the larger the plant the better, but there are practical limitations on plant size.

Table B-5 shows the range of unit energy consumption for the major types of kiln systems.



*TONS OF EQUIVALENT PRODUCTION ARE USED

Source: Portland Cement Association and Arthur D. Little

Figure B-7. Percent Distribution of Unit Energy Consumption, 1972 and 1974

TABLE B-4

ENERGY EFFICIENCY
(10^6 Btu/ton finished portland cement)

	All Plants		Wet Plants		Dry Plants	
	1972	1974	1972	1974	1972	1974
I. Plant Age						
<10 years	7.57	7.04	--	7.4[a]	--	6.8*
10-40 years	7.54	7.56	--	--	--	--
>40 years	8.79	8.62	--	9.1[a]	--	7.9*
II. Plant Size						
<300 x 10^3 tons	8.32	8.08	8.69	8.67	7.57	7.18
300-600 x 10^3 tons	7.83	7.77	8.41	8.41	6.93	6.87
>600 x 10^3 tons	7.08	6.96	7.14	7.28	6.98	6.69

*Based on 10 plants 40 years old or older and 25 plants less than 10 years old.

Source: Portland Cement Association, May 1974 and June 1974

TABLE B-5

ENERGY CONSUMPTION BY TYPE OF KILN

	10^6 Btu/ton Clinker
Long Wet Kiln with Chains	4.7-9.45
Long Dry Kiln	5.0-7.8
Long Dry Kiln with Chains	3.9-6.1
Long Dry Kiln with Waste-Heat Boiler	4.95-6.1
Short Dry Kiln with Grate Preheater	3.55-3.85
Short Dry Kiln with Suspension Preheater	2.85-4.45

Source: Iammartino, N.R., Chemical Engineering

APPENDIX C

CURRENT POLLUTION PROBLEMS AND EFFECTIVENESS OF AVAILABLE POLLUTION CONTROL TECHNOLOGY

1. AIR POLLUTION

a. Emissions from Cement Manufacturing Plants

The major source of particulate emissions in cement plants is the kiln. Dust is generated in kiln operations by the hot combustion gases entraining feed particles. Also involved is the tumbling action within the kiln, the liberation of gases during calcination, which tends to expel particles into the gas stream, and the condensation of material that is volatilized at the firing end of the kiln. Volatilization and condensation generally produce smaller particles than the mechanical processes, thereby increasing the difficulty of the air pollution cleanup problems.

In the wet process a dryer is not used. However, in some dry process plants the raw materials are first dried. The concentration of dust in the dryer exit gases is related to the velocity of the gases, the quantity and size of the fine particles, and their degree of dispersion in the gas stream. The volume of the flue gas from the dryer depends on the moisture content of the feed material.

As the clinker is discharged from the lower end of the kiln, it is passed through a clinker cooler that reduces the temperature of the clinker. The clinker cooler represents another source of airborne pollutants in the cement plants.

Emissions from the crusher area depend on the type and moisture content of the raw material and the characteristics and type of crusher. If the material has a high moisture content, it may not be necessary to provide dust control, due to very little emissions.

b. Air Pollution Control Laws

The Environmental Protection Agency has established new sources standards in some industries. The cement industry is one of these. These standards are applicable to kiln and clinker coolers and facilities; they are also applicable to modified equipment.

(1) Kiln

- The maximum 2-hour average discharge of particulates shall be 0.3 lb/ton of feed to the kiln.
- The maximum discharge of particulates shall be limited to 20% opacity, except where the presence of uncombined water is the only reason for failure to meet the requirements.

(2) Clinker Cooler

- The maximum 2-hour average discharge of particulates shall be limited to 0.1 lb/ton of feed to the kiln.
- The maximum discharge shall be limited to 10% opacity.

(3) Other Facilities

The maximum discharge shall be limited to 10% opacity. Cement plants scheduled for construction after August 17, 1971, were assumed to be subject to national standards of performance.

While existing cement plants (starting construction before August 17, 1971) are subject to state air pollution regulations, the regulations vary from state to state. In the cement industry, the federal standards for new sources may be used as an average of state standards for existing plants. The only difference is that the electrostatic precipitator has an acceptable collection efficiency in existing plants, whereas it will not be acceptable according to the new source performance standards.

c. Control Practices and Equipment for Cement Plants

(1) Control Practices

Particulate emissions can be adequately controlled in the cement industry by proper selection of dust control equipment. Particulate emissions as low as 0.03 to 0.05 gr/scf have been obtained in newly-designed, well-controlled plants.

The hot kiln gases are the main source of emissions and they present a major problem because gas volumes are large; they contain acid gases such as H_2S and SO_2, varying amounts of H_2O, and are in a temperature range usually above 500 or 600°F. A kiln producing 20 tons of cement clinker per hour will produce about 240,000 pounds of exit gases per hour, or about 92,000 acfm.

(2) Control Equipment

(a) Multicyclones

Although a number of types of dust collectors are used in the cement industry, only the high-efficiency collectors, such as the electrostatic precipitator and fabric filter sometimes used in series with inertial collectors, effectively collect fine dust. The multicyclones alone are not an acceptable means of reducing dust emission from the kiln to the atmosphere, since they can only be expected to remove about 70% or all the coarser particles.

(b) Electrostatic Precipitators

In a wet process plant, the performance of an electrostatic precipitator is greatly enhanced by the extra water vapor in the exhaust gases from the slurry. Dry process kilns do not have this water in the feed, so it often is necessary to add water as an aid to precipitator operation. In the past, the operation of electrostatic precipitators has not been entirely satisfactory because of decreasing efficiency over extended periods due to the effects of the cement dust on the high-voltage components. Also, when kilns have been shut down and then restarted, it has been necessary to bypass the electrostatic precipitator for periods up to 24 hours because of the danger of explosion from combustible gas or coal dust.

(c) Fabric Filters

Fiberglass baghouse filters have had much success in controlling kiln emissions. Bag life averages 18 months or more. A big plus in baghouse installations is the fact that duct designs are simple and uncomplicated, requiring little study for the flow of gases when compared with the frequently complicated model studies necessary for good gas flow patterns in the electrostatic type dust collector.

Moisture condensation in glass fabric filters can present problems. However, dew point temperatures are normally avoided by proper application of insulation to ducting, etc., and by proper operation to avoid condensation.

Investment and capital cost estimates were based on the following:

- For dry-process rotary kilns, assumed that glass fabric filters would be used.
- For existing wet-process rotary kilns, we assumed that electrostatic precipitators would be used. Investment costs for wet process kilns were estimated by assuming a migration velocity of 0.35 ft/sec and a gas volume as predicted by a linear regression equation.
- We assumed glass fabric filter controls for raw material dryers and clinker coolers. For the clinker we further assumed that only the secondary section would be vented to a control system, while air from the primary section would be returned to the kiln.

The cost data represent March 1975 dollars; we used the Engineering and News Record Index (ENR Index) to update the cost data obtained from various sources. The capital cost is extrapolated by using the six-tenths rule. Depreciation was assumed to be straight line over 20 years. Return on investment (ROI) was arbitrarily estimated to be 20% of the capital investment.

d. Effect of Fuel Used in the Kiln on Emissions

Gaseous emissions from the combustion of fuel in the kiln are usually not sufficient to create significant air pollution problems. Most of the sulfur dioxide formed from the sulfur in the fuel is recovered as it combines with the alkalies and also with the lime when the alkali fume is low. Tests of the kiln exit gases from one portland cement plant burning 2.8% sulfur coal showed a concentration of sulfur dioxide ranging from 6 to 39 ppm. Nitrogen oxides can form at kiln temperatures of 2,600-3,000°F and may be of some concern in areas that experience photochemical-type air pollution, but no federal restrictions exist or are anticipated.

TABLE C-1

SULFUR DIOXIDE EMISSION FACTORS FOR CEMENT KILNS*

	Dry-Process Kiln	Wet-Process Kiln
Gas Combustion kg/10^3 ton	Negligible	Negligible
Oil Combustion kg/10^3 ton	2.1S	2.1S
Coal Combustion kg/10^3 ton	3.4S	3.4S
Mineral Source kg/10^3 ton	5.1	5.1

[*] The sulfur dioxide factors presented take into account the reactions with the alkaline dusts when no baghouses are used. With baghouses, approximately 50% more SO_2 is removed because of reactions with alkaline particulate filter cake. The total SO_2 from the kiln is determined by summing emission contributions from the mineral source and the appropriate fuel.

2. WATER POLLUTION

In discussing wastewater characteristics, regulatory constraints, and wastewater treatment technology/economics, it is necessary to distinguish between wet and dry process plants and between leaching and non-leaching plants, for each has its own set of wastewater effluent problems, guidelines, and recommended treatments. Dry process plants outnumber wet process plants, and non-leaching plants outnumber leaching plants. The anticipated energy-saving process changes within the cement industry apply to the dry process, non-leaching type cement plant; and for this reason, water pollution considerations of this report are almost entirely focused on the dry process, non-leaching plant.

a. Sources of Wastewater

Cement plants, in general, have 2 major sources of wastewater:

- Noncontact cooling water;
- Wastewater previously in contact with raw material, final product, or discarded cement dust.

Depending on the type of plant, wastewater may come in contact with raw material, product, or discarded dust, either directly as an intended part of the manufacturing process, or indirectly, either as plant cleaning water or as surface run-off from accumulated piles of discarded cement dust.

(1) Wet Process, Leaching Plants

Wet process plants feed raw material to the kiln in the form of a slurry. The slurry water is subsequently evaporated in the kiln and therefore should not constitute a discharge.

The relatively constant volume of water in the preparation of slurry averages 260 gal/ton.

At a few plants, excess water containing a high concentration of suspended solids is discharged from the slurry thickeners. This constitutes a nonessential discharge and is easily avoided by recycling the water to make the slurry. Other losses of slurry may occur due to poor maintenance of pumps, which become worn and develop leaky seals. If not controlled, the resulting spillage may result in a waste discharge with high solids.

In "leaching" plants, soluble alkalies from collected kiln dust are removed by leaching so that portions of the dust can be returned to the kiln as recovered raw material. In all plants employing leaching, the overflow (leachate) from this operation is discharged. For all plants that employ leaching, the wastewaters from the leaching step are very similar, varying to some extent in concentration of individual constituents because of differences in raw materials. Wastewaters from leaching operations are high in pH and alkalinity, and contain appreciable amounts of suspended solids and dissolved solids (calcium, potassium, chlorides, and sulfates). Of all the wastewater streams associated with the manufacture of cement, the leachate overflow is environmentally the most objectionable.

(2) Dry Process, Non-leaching Plants

In the dry process, non-leaching plant, there are but two major wastewater streams: noncontact cooling water, and overflow/run-off water from discarded dust storage piles.

In terms of volume, the largest wastewater stream is usually the noncontact cooling water. This water is used to cool bearings on the kiln and grinding equipment, air compressors, burner pipes and the finished cement prior to storage or shipment (Table C-2). While cooling water is mostly noncontact, it can sometimes become polluted as a result of poor water management practices. This pollution may include oil and grease, suspended solids, and even some dissolved solids. If cooling towers are used, blowdown discharges may contain residual algicides.

In non-leaching plants discarded cement dust is not recovered; instead it is usually allowed to accumulate in large storage ponds or piles. (In many cases, particularly in older plants, discarded dust is returned to the quarry from where it originated.) Often, the discarded dust is transported to the pond in the form of a slurry. If the plant is located in a region of net precipitation, periodic overflows from the storage areas or ponds can occur. Discharges can also occur from use of excessive slurry water and other poor water management procedures. The characteristics of dust storage area overflow and run-off are not unlike those of leachate overflow from leaching plants, in that the wastewater will be high in pH, alkalinity, and dissolved solids. The volume of dust storage area overflow or run-off is very much a function of site-specific conditions.

TABLE C-2

REPORTED COOLING WATER USAGE IN CEMENT PLANTS

Use	Average Flow (gal/ton of product)	Number of Plants	Range Minimum	Range Maximum
Bearing cooling	284	39	1.0	1,530
Cement cooling	200	22	0.5	985
Clinker cooling	23	12	0.6	64
Kiln-gas cooling	85	4	24	203
Burner-pipe cooling	70	2	68	72

Source: "Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Cement Manufacturing Point Source Category", U.S. Environmental Protection Agency, EPA 440/1-73/005

(3) Miscellaneous

All cement plants have some accumulation of settled dust on the plant property, and this dust may show up in the wastewater in a number of ways. Many plants spray water on the roads to prevent the dust from becoming airborne by truck traffic. Most plants also routinely wash accumulated dust off the trucks. At some plants, certain parts of the plant areas are also washed down to remove accumulated dust. The amount of water used for these purposes varies widely, ranging from 250 to 2,500 gpd. Some of this water undoubtedly evaporates, but depending on the topography of the plants, some of this water may drain into storm sewers or natural waterways.

Water from process area surface run-off after rain may also be laden with the dust that accumulates on the plant site. Run-off from dust piles, coal piles, and raw material piles may also become contaminated. Plants with boilers, cooling towers, and intake water-treatment facilities have blowdown and backwash discharges associated with these operations. Relatively few of the plants employing wet scrubbers for air pollution control have a wastewater stream consisting of spent scrubber water.

A summary of reported water usage within the cement industry is presented in Table C-3.

TABLE C-3

WATER USAGE FOR THE CEMENT INDUSTRY

Use	Number of Plants	Reported Flow Average	Minimum	Maximum	Units
Cooling	117	450	5	21,000	gal/ton of Product
Raw Material Washing and Beneficiation	4	29	0.6	118	gal/ton of Raw Material
Process	78	29	0.7	108	gal/ton of Product
Dust Control	13	250	72	510	gal/ton
Dust Leaching	11	703	627	773	gal/ton of Dust
Dust Disposal	5	55	2.3	140	gal/ton of Product
Wet Scrubber	3	8,100	1,200	12,300	gal/ton of Product

Source: "Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Cement Manufacturing Point Source Category", U.S. Environmental Protection Agency, EPA 440/1-73/005

b. Wastewater Characteristics

While a wide variety of inorganic chemical constituents are present in both leaching and non-leaching plants (Table C-4), it was EPA's decision that none are of sufficient concern to warrant the setting of specific limitations for those species. Pollution control measures for this industry are designed primarily to remove suspended solids, control pH, and to limit the temperature rise of water going through the plant.

As Table C-4 shows, the overall waste loading from non-leaching plants is much lower than that of leaching plants.

With the exception of lead and chromium, significant loadings of heavy metals have not been generally detected in the wastewaters from cement plants. The plants that do have lead and chromium present appear to be isolated cases.

c. Regulatory Constraints

Briefly, the Effluent Guidelines for the Cement Industry* pertaining to dry process, non-leaching plants are solely intended to limit the quantity of suspended solids discharged, reduce thermal pollution from discharged cooling water, and to maintain the pH within acceptable limits.

TABLE C-4

COMPARISON OF WASTE LOADINGS FOR LEACHING AND NON-LEACHING SUBCATEGORIES

Parameter	Units	Mean Value for Leaching Subcategory	Number of Plants	Mean Value for Non-leaching Subcategory	Number of Plants
Alkalinity	lb/ton	2.76	10	0.17	61
BOD, 5 day	lb/ton	0	9	0	57
COD	lb/ton	0.06	9	0	53
Total Solids	lb/ton	14.99	10	0.63	61
Total Dissolved Solids	lb/ton	13.24	10	0.56	60
Total Suspended Solids	lb/ton	1.81	10	0	58
Total Volatile Solids	lb/ton	1.65	8	0	57
Ammonia	lb/ton	0	8	0	53
Kjeldahl Nitrogen	lb/ton	0	8	0	52
Nitrate Nitrogen	lb/ton	0	8	0	53
Phosphorus	lb/ton	0	8	0	55
Oil and Grease	lb/ton	0	4	0	47
Chloride	lb/ton	2.40	6	0	56
Sulfate	lb/ton	7.33	6	0	56
Sulfide	lb/ton	0	4	0	41
Sulfite	lb/ton	-	0	0	5
Phenols	.001 lb/ton	0	4	0	47
Chromium	.001 lb/ton	0.16	6	0	51
Acidity	lb/ton	-	0	0	6
Total Organic Carbon	lb/ton	-	0	0	4
Total Hardness	lb/ton	4.41	4	1.73	21
Fluoride	lb/ton	0	1	0	5
Aluminum	.001 lb/ton	1.28	3	0.02	10
Calcium	lb/ton	1.93	4	0.19	18
Copper	.001 lb/ton	-	0	0	5
Iron	.001 lb/ton	9.53	3	0.31	15
Lead	.004 lb/ton	1.98	2	0	3
Magnesium	lb/ton	0.03	4	0.31	15
Mercury	.001 lb/ton	-	0	0	3
Nickel	.001 lb/ton	-	0	0	4
Potassium	lb/ton	6.40	4	0.15	11
Sodium	lb/ton	0.74	4	0.48	12
Zinc	.001 lb/ton	0	2	0	9

Source: ".....Effluent Guidelines Development Document--Cement Industry.....", U.S. Environmental Protection Agency, EPA 440/1-73/005

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*"Effluent Guidelines and Standards - Cement Manufacturing," 40 CFR 411, Federal Register, February 20, 1974.

Effluent guidelines are divided into two parts, those pertaining to wastewater discharged from the plant itself (defined as "Subpart A-Non-leaching Subcategory) and those pertaining to materials storage pile run-off (Subcategory C). For both these subcategories the BPTCA level (Best Practicable Control Technology Currently Available 1977) and the BATEA level (Best Available Technology Economically Achievable) are the same, and are listed below:

Subpart A - Non-leaching Subcategory

	BPCTCA (1977) and BATEA (1983)
Effluent Characteristics	Effluent Limitations (max. for any one day) (lb/1000 lb of product)
Total Suspended Solids	0.005
Temperature (heat)	Not to exceed 3°C rise above inlet temperature
pH	Within the range from 6.0 to 9.0

Subpart C - Materials Storage Piles Run-off Subcategory

	BPCTCA (1977) and BATEA (1983)
a. Effluent Characteristics	Effluent Limitation
Total Suspended Solids	Not to exceed 50 mg/liter
pH	Within the range from 6.0 to 9.0

b. Any untreated overflow from facilities designed, constructed, and operated to treat the volume of run-off from materials storage piles which is associated with a 10-year, 24-hour rainfall event shall not be subject to the pH and TSS limitations stipulated above.

d. Treatment Technology and Costs

In order for the dry process, non-leaching cement plant to achieve the recommended effluent discharge levels, it is generally necessary for the following measures to be implemented:

- Isolation of cooling water circuits from possible sources of pollution and reduction of discharged cooling water temperature by means of either cooling towers or spray ponds; and
- Diking, collection, clarifications, and neutralization of all wastewater from discarded dust and material storage areas.

On the basis of these requirements, we have prepared wastewater treatment cost estimates for the specific 1350-tpd base case dry process, non-leaching cement plant (Table C-5) in accordance with the following design basis:

- Noncontact cooling water flowrate = 648,000 gallons
- Spray pond area = 1 acre
- Dust generation @ 7% of raw material feed, or 140 tpd. Run-off control measures are based on a 10-year accumulation, which at a 20-ft depth amounts to 10.6 acres. Of the total dust, 15% is expected to be soluble.
- Discarded dust storage area is diked to contain and collect the overflow caused by precipitation run-off. The amount of run-off is basically the amount of precipitation in excess of evaporation, which of course varies from location to location. For the purpose of these estimates, a run-off rate resulting from precipitation in excess of evaporation of 4 inches per year was used. This results in a flowrate of 3100 gpd average.
- Overflow wastewater treatment system consists of a 500,000-gallon holding basin to contain heavy stormwater surges plus a clarifier with acid feed equipment (both capable of treating a flowrate of 20,000 gpd).

Our cost estimates are for the specific example of a dry process, non-leaching cement, and are in no way intended to represent industry-wide wastewater treatment costs. Wet process leaching plants can incur substantially higher costs due to greater wastewater volumes and waste loads.

TABLE C-5

WASTEWATER TREATMENT COSTS: BASE CASE CEMENT PLANT

Basis
1350 tpd Cement Production
330 Operating Days Per Year

CAPITAL INVESTMENT - \$519,000

	Annual Quantity	Cost Per Unit Quantity	Quantity Per Ton of Production	Unit Cost (\$ Per Ton of Product)
VARIABLE COSTS				
Operating Labor (including overhead)	2630 man-hr	\$12/hr	0.0059	0.0709
Maintenance (including Labor & Mtls)				0.0467
Chemicals				
Sulfuric acid	14 tons	\$100/ton	$3.1x10^{-5}$	0.0031
Electrical Power	360,000/ kWh	\$0.02/ kWh	0.81	0.0162
TOTAL VARIABLE COST				0.1369
FIXED COST				
(Depreciation @ 5%)				0.0584
(Taxes & Insurance @ 2%)				0.0233
TOTAL FIXED COST				0.0817
TOTAL ANNUAL COST				0.2186
RETURN ON INVESTMENT @ 20%				0.2330
TOTAL				0.45/ton

Notes:

1) Capital investment adjusted to 1975 level (ENR Construction Cost Index = 2126)

2) Wastewater treatment includes:
   a) Non-contact cooling water thermal pollution control via spray pond
   b) Dust pile runoff containment, collection, clarification, and neutralization

3) Estimates are for the specific example of a dry-process, non-leaching cement plant and are in no way intended to represent industry-wide wastewater treatment costs.

Source: Arthur D. Little, Inc. estimates

APPENDIX D

FLASH CALCINING SYSTEMS

1. JAPANESE

a. Ishikawajima Harima Heavy Industries

The IHI suspension flash preheater system was developed by IHI and Chichibu Cement. The suspension preheater portion of this system receives raw feed in the conventional manner and the raw feed progresses down through the first three stages of the preheater in a conventional manner. The product from the third stage, instead of discharging into the fourth and final stage, is discharged into the flash furnace, which contains several burners mounted in the furnace roof. The flash furnace is a cyclonic suspension furnace with gas inlet at the bottom and tangential gas and calcined raw feed outlet at the top.

One of the important features of the IHI suspension flash preheater is the addition of high-temperature preheated air, taken from the midsection of the grate-type clinker cooler, to the combustion gas leaving the rotary kiln to form the atmosphere in which the flash furnace fuel is burned. This permits the fuel in the rotary kiln to be burned with the appropriate minimum quantity of excess air, thus optimizing the burning conditions in the kiln.

A main disadvantage of providing all of the combustion air to the flash calcining vessel or furnace by using sufficient excess combustion air within the rotary kiln is the high volumetric flow rate of gas and its attendant high spatial velocity within the rotary kiln. Consequently, it is desirable, if not necessary, to provide the combustion air for the flash furnace from a source other than the excess air contained in the combustion gases leaving the rotary kiln. A second disadvantage is that the high volumes of combustion gas and excess air passing through the rotary kiln do not concentrate the volatilized alkalies in that gas stream, thereby negating the removal of alkalies by use of a bypass.

The design of the IHI suspension flash preheater avoids these difficulties by taking hot air from the center of the clinker cooler and conveying it through a separate refractory-lined duct, located parallel to the kiln, and mixing this hot air with the combustion gases leaving the rotary kiln. This mixture of combustion gas and preheated air from the clinker cooler is then introduced into the flash furnace. The flow rate of combustion gases through the rotary kiln and the preheated air through the secondary air duct between the clinker cooler and the flash furnace is provided by the suction from the induced draft fan, which is the prime air mover through the entire kiln/flash calciner/preheater system. The proper balance of air flow to the kiln and the flash furnace is controlled by:

- a constricted portion of the kiln extract duct, which functions as an orifice, to achieve a fixed gas flow resistance on the outlet of the kiln combustion gases; and
- an adjustable damper in the secondary air duct, which can control the pressure drop through this duct, and thereby balance the air flow system.

This system permits operation without a secondary air fan, which generally provides hot secondary combustion air from the clinker cooler to the rotary kiln. In the conventional preheater kiln or long non-preheater kiln system. the temperature limitation of this fan prevents the use of secondary air temperatures as high as they actually could be. Because no secondary air fan is required in this system, the hottest possible secondary air from the cooler can be used for the rotary kiln, thereby further reducing the overall heat consumption.

This system for controlling and balancing the flow of hot secondary air and combustion gases has been demonstrated at over 12 suspension flash preheater facilities which IHI has built, and which are now in operation. The IHI design also eliminates the need for a fan to move the hot air from the clinker cooler through the secondary air duct. This results in the use of the hottest available air from the mid-section of the clinker cooler to be sent to the flash furnace for the raw feed precalcining, which further maximizes the heat recuperation from the clinker cooler.

At a typical IHI suspension flash preheater system, the temperature of the hot combustion gases leaving the rotary kiln is higher than the temperature of the air in the secondary air duct, at the point where these two hot gas streams are mixed, just prior to their entry into the bottom of the flash furnace. The temperature of the hot combustion gases leaving the rotary kiln is about 2050°F, while the temperature of the hot air in the secondary duct, at the point of mixing, is approximately 1380°F. The mixture of these two streams results in a cooling of the hot combustion gases from the rotary kiln. This sudden temperature reduction, especially in this temperature range, would tend to cause the solidification of alkali-coated raw material and dust particles, which would tend to build up on the walls of ducts and the internal surfaces of the flash furnace. Therefore, one of the design features of the IHI system is that the hot secondary air and the kiln gases are sufficiently well-mixed in a short enough time and in a way which prevents the build up of solid alkali-rich materials.

Hot secondary air and hotter kiln combustion gases mix as they tangentially enter the bottom of the flash furnace. The gases spiral upward through the flash furnace and exit, also tangentially. The raw material inlet is located in the roof of the flash furnace at a point which maximizes the retention time of the raw material inside the flash furnace vessel and produces the most uniform dispersion of the calcining raw material within the hot combustion gases generated by the burning fuel. All of the plants thus far have used oil in the flash furnace but Fuller and IHI are presently conducting tests for the use of coal.

b. Onoda Cement-Kawasaki Reinforced Suspension Preheater System

The Onoda/Kawasaki flash calciner is called the "reinforced suspension preheater system" (RSP). The main features of the RSP system are similar to the suspension flash preheater system developed by IHI. The principal difference between the IHI and the Onoda/Kawasaki systems is that the kiln exit gases do not pass through the flash calcining vessel; instead, they mix with the precalcined raw material and combustion gases coming from the flash calcining vessel on their way to the Stage 4 cyclone. The only gas going to the flash calcining vessel is the hot preheated secondary combustion air coming from the clinker cooler. Since the air required for the combustion of the fuel introduced into the flash calcining vessel is provided directly from the clinker cooler without mixing with kiln gases, it is reported that the higher concentration of oxygen present in that vessel provides more stable and positive combustion than the IHI system. However, this higher concentration of oxygen is probably responsible for a higher concentration of NO_x formed within the flash calcining vessel. This would tend to negate one of the main environmental advantages ascribed to the flash calcining system.

There are two main parts to the flash calcining vessel used by the RSP and the secondary hot air stream from the clinker cooler is divided into two parallel streams. One of these secondary air streams goes to the swirl burner, in which an ignition burner operates. The other stream of hot secondary air goes to the swirl calciner, in which the single main firing burner is operated.

The final remaining major difference between the IHI and the RSP systems is that the latter requires an induced draft fan to provide the hot secondary air from the clinker cooler at a sufficiently high pressure for its introduction into the swirl burner and swirl calciner. The operating temperature limitations of a fan in this secondary air stream limit the temperature of the hot air taken from the clinker cooler to a level which is below the maximum which could be taken from the cooler. This would tend to reduce the heat recuperated from the clinker cooler, and, consequently, increase the overall fuel energy required to make cement clinker by this process.

c. Mitsubishi Fluidized Calcinator

Although the basic characteristics and the process conceptual goal of the Mitsubishi fluidized calcinator (MFC) are equivalent to both the IHI and the Onoda/Kawasaki flash calciner processes, this third alternative has some significant differences which put it in a quite different category.

The primary feature which sets this concept apart from the preceding two is that the preheated raw material is calcined in a fluidized bed instead of in a vortex-type suspension vessel. Secondly, only a fraction of the preheated raw material is sent to the precalcining or flash-calcining, fluidized-bed vessel, whereas the preceding two processes are designed to operate with 100% of the preheated raw material fed to the flash calcining vessel. Presently, only 20% of the total raw feed is diverted to the fluidized-bed calcining vessel. Although this material is precalcined to an extent of 90% when it is recombined with the remaining 80% of the preheated raw feed, the precalcined mixture which is fed to the rotary kiln has been calcined to an extent of only 55%. However, Mitsubishi is currently working toward increasing the bypass percentage to 50% or possibly higher. But at present this system remains a hybrid between the flash calcining system and the suspension preheater system. The available literature provides no basis for a prediction of how much of the raw feed can be passed through the fluidized-bed, flash calcining step.

When the fluidized bed is fired with oil about one-third of the air required for complete combustion of the oil is introduced along with the oil through burners which are submerged below the fluidized-bed surface. The remainder of the two-thirds of the required combustion air is introduced above the bed. Therefore, a significant amount of combustion takes place above the fluidized bed. This is probably necessary because of the small particle size of the raw feed, and the consequently low fluidizing velocity.

One of the present advantages of the system is that Mitsubishi has reported the use of coal as the sole fuel in the fluidized-calcining vessel. Although Fuller Company and IHI are presently conducting development programs aimed at the use of coal in their flash-calcining vessels, we understand that Mitsubishi is the only company which has successfully used coal as the only fuel in the flash-calcining-vessel section of their system.

Fluidization of the preheated raw material in the fluidized calcinator is done with hot air from the clinker cooler which has first passed through a cyclone-type dust collector to remove the fine clinker dust.

An interesting benefit of the MFC process is that materials containing fuel value but not normally used for fuel can be successfully burned in the fluidized calcinator. For example, waste material from coal dressing operations has been effectively burned. Such refuse with a heating value of between 2500 and 5000 Btu/lb has been successfully burned with the ash forming part of the raw material and being converted to clinker. Such coal dressing refuse, in addition to being unsuitable as the sole fuel for firing a conventional rotary kiln system, is also unsuitable as a supplemental fuel additive, blended with coal or another fuel, because the refuse will cause a decrease in burning temperature, has a tendency for kiln ring formation and the lack of suitable mixing between the ash from the burned coal dressing refuse and the clinkering raw material in the firing zone of the rotary kiln produces a variation in clinker quality which is unacceptable. Actual commercial operation of this system began in December, 1971, with a significant increase in kiln capacity, and in system availability.

2. EUROPEAN

a. Polysius System

Polysius has modified their Dopol suspension preheater system in which all of the air required for combustion in the precalciner is contained in the rotary kiln exit gas as excess air. The kiln exit gases enter the bottom of the calcining shaft where a number of burners supply up to 50% of the total process heat.

This Polysius system was developed in conjunction with Portland-Zementwerk Dotternhausen, in Southern Germany, expressly for the purpose of utilizing an oil shale raw material component successfully in a suspension preheater without the sticking, clogging, and other solid material buildups which create severe operating problems in suspension preheaters when the raw material feed contains fuel values. Also, this cement company wished to use the fuel values of the oil shale in its raw material feed to effectively reduce the amount of purchased fuel used in the rotary kiln. Both of these objectives were reached by the successful development of the Polysius version of the flash calciner.

The salient features of the Polysius system, as embodied in the full-scale commercial operation at Dotternhausen, are:

- Coal can be utilized in the flash calciner.
- No kiln bypass duct is used.
- Planetary coolers can be used since all of the combustion gas is conducted through the rotary kiln.
- Raw material containing fuel values, such as oil shale, can be successfully used.
- Six years of actual plant experience have been obtained.

b. F.L. Smidth System

In Denmark, F.L. Smidth & Company has been developing a flash calcining system. Although it is claimed that a fluidized bed of raw material and fuel exists in the bottom of this precalciner, it appears that most or even all of the combustion of fuel, and calcination of the raw material, occurs in the toroidal recirculation zone which exists in most of this vessel, where the raw feed particles, after being preheated, are calcined in suspension.

The kiln exit gas passes up through a conventional four-stage suspension preheater and the preheated air from the clinker cooler passes through the secondary air duct which runs parallel to the kiln and then enters a second and separate suspension preheater which is equipped with a flash calciner. The preheated raw material from the discharge of stage four of the suspension preheater system is passed through into the flash calciner and is precalcined along with the preheated raw material entering the flash calciner from stage three of the flash calciner-equipped suspension preheater. In this way, the two high temperature gas streams are kept separate until they have passed the two separate induced draft fans and the distribution of the combustion air from the kiln and the clinker cooler secondary air can be regulated by means of the two separate fans.

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